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Measurement of Irrigation Water

Eldon M. Stock

Bulletin No. 5 June, 1955

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Professor of Civil Engineering and Collaborator,
Utah Cooperative Extension Service

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FOREWORD

Although irrigation has been practiced in Utah for more than one hundred years, irrigation water still is being distributed to farmers with little or no thought about its measurement. A farmer would not think of buying or selling other farm commodities, such as hay, grain, beef cattle, or dairy products, without weighing or accurately measuring them, but at the same time he is often content to accept and pay for the irrigation water received with little or no knowledge as to the actual amount received, or whether or not he is receiving the amount he is entitled to.

Measurement of irrigation and drainage waters in Utah by irrigation companies, irrigation and drainage districts, and by cities and towns having irrigation systems is of paramount importance to conservation of the state's water and soil resources. Systematic water measurements properly recorded, interpreted, and used constitute the foundations upon which increasing efficiencies of water conveyance, application and use must be constructed. Higher efficiencies in the various phases of irrigation will conserve water and decrease the need for and the cost of land drainage.

The purpose of this bulletin is to present, in a brief and simple form, a discussion of the more common methods of water measurement together with descriptions of the devices used and useful tables or graphs.

Water measurement is based on fundamental principles of hydraulics, but the practical application of these principles necessary to the actual measurement of stream flow requires no special knowledge of hydraulics or mathematics beyond simple algebra. The technique of using these devices and the graphs or tables accompanying them can be mastered readily by farmers or those responsible for regulation and distribution of water to the farmers.

It is hoped that this simplified presentation of information on water measurement will encourage more irrigation companies and farmers to measure their irrigation water and to strive to increase efficiencies in the use of existing water supplies. This bulletin should be useful not only to irrigation farmers, water masters and ditch riders, but also to county agricultural agents, agricultural research workers, attorneys and engineers.

J. E. CHRISTIANSEN, *Director*
Engineering Experiment Station

CARL FRISCHKNECHT, *Director*
Utah Cooperative Extension Service

ACKNOWLEDGEMENTS

This bulletin is a revision of Bulletin No. 2 of the Utah State Engineering Experiment Station, and is a compilation of information gathered from published sources, together with that gathered from the author's practical experience. The author is especially indebted to the Utah State Engineering Experiment Station for material from Bulletin No. 2 by Wayne D. Criddle and Eldon M. Stock; to the Utah State Agricultural Experiment Station for material from Circular 77 by George D. Clyde; to the University of California Agricultural Experiment Station for material from Bulletin No. 588 by J. E. Christiansen; to the Colorado Experiment Station for material from Bulletins 423 and 426-a by Ralph L. Parshall; and to the U. S. Department of Interior, Bureau of Reclamation, for information on constant head orifice turnouts.

The present bulletin incorporates most of the tables contained in Extension Bulletin No. 166, "Measurement of Irrigation Water–A Handbook of Discharge Tables for Ditch Riders and Irrigators" by James R. Barker, which was prepared for use with Engineering Experiment Station Bulletin No. 2. The use of this material is acknowledged.

The Division of Irrigation, S. C. S., has, alone and in cooperation with the various state experiment stations, gathered considerable information on methods and devices used in measuring irrigation water. For the use of some of this information, the author is indeed grateful.

The author is especially grateful to Wendell M. Keck for editing the manuscript, and to A. A. Bishop, C. H. Milligan, and James R. Barker for reviewing the manuscript and for many helpful suggestions; and to Director J. E. Christiansen, under whose direction the bulletin was written.

MEASUREMENT OF IRRIGATION WATER

by

Eldon M. Stock[1]

INTRODUCTION

Water is the limiting factor in Utah's agricultural development. In spite of the admitted value of water, the farmer knows less about its measurement than about any of the other commodities he handles. He knows how to measure his land, weigh his crops and count his cattle, but he has little conception of how to measure his most valuable asset, irrigation water. The importance of water measurement is not appreciated until the water supply becomes over-appropriated and users begin interfering with each other's rights. Expensive litigation, which nearly always follows controversies over water, is gradually convincing the farmer that water should be measured as carefully as beets, grain, sugar, coal, flour or any other commodity he buys or sells.

The building of storage reservoirs for utilizing flood water and winter flow has brought into use new irrigation conditions that depend for their success on the measurement of water. The storage reservoir may be considered a bank in which the farmer deposits, instead of gold, silver or currency, a certain volume of water that he will use later for irrigation. He draws this water from storage as he needs it, just as he draws his money from the bank. To protect the various rights in the reservoir, the water must be measured in and out.

Even if grown on the same soil, different crops require different amounts of water. Also, different soils require different amounts of water for the same crop. To utilize water economically, the farmer must know how much water to apply and how to measure the amount of each application.

The farmer is more and more recognizing the need for and value of water measurement as is evidenced by the many inquiries that come to the college for information concerning this subject. The demand for information will increase as farmers become more conscious of the need for measuring irrigation water in order to use it efficiently and also to defend their water rights.

The purpose of this bulletin is to present in simple terms the essential elements of water measurement to irrigation farmers, ditch riders, water masters and others who wish to measure irrigation water. Frequent references are made to more technical publications; thus, anyone wishing to do so may

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determine the basis of the simplified principles of water measurement. Tabular and graphical presentation of the solution of the various flow formulas is used throughout this bulletin because these solutions are simple and have a wide application.

TERMS USED IN WATER MEASUREMENT

Water is measured under two conditions—at rest and in motion.

Water at rest—that is, in reservoirs, ponds, soil and tanks—is measured in units of volume such as the gallon, cubic foot, acre-foot and acre-inch.

Measurement of water in motion—that is, flowing in rivers, canals, pipe lines, ditches and flumes—is expressed in rate of flow: gallons per minute (g.p.m.), cubic feet per second (c.f.s.), acre-feet per day, acre-inches per hour, and miner's inches.

It is important that the distinction between a unit of volume and a unit rate of flow be kept in mind. For instance, a cubic foot is a definite volume of water such as would be held in a container 1 foot wide, 1 foot broad and 1 foot deep, whereas a cubic foot per second is a flow which would fill the cubic-foot container once every second as long as the flow continued.

Acre-foot—An acre-foot is a volume of water sufficient to cover an acre 1 foot deep. It is equal to 43,560 cubic feet.

Acre-inch—An acre-inch is a volume sufficient to cover an acre 1 inch deep. It is equal to one-twelfth of an acre-foot or 3630 cubic feet.

Cubic foot per second (c.f.s.)—This is a rate unit and represents an exact and definite quantity of water per second. It is the equivalent of a stream 1 foot wide and 1 foot deep flowing at an average rate of 1 foot per second.

Gallon per minute (g.p.m.)—This is a rate unit and represents a definite quantity of water per minute. It is the equivalent of a stream that would fill a gallon measure once each minute.

Miner's inch—Miner's inch is a rate of flow It is a variable unit having different meanings in different states. (See Table 1.) The Utah miner's inch is a quantity of water flowing freely through an opening 1 inch square, the center of which is 4 inches below the surface of the water standing above the opening. It is equivalent to a flow of 9 gallons per minute or one-fiftieth of a cubic foot per second. *The miner's inch is not a stream of water 1 inch deep and one inch wide, regardless of the height of water surface behind the opening.* The miner's inch is a convenient unit for measuring small streams, but where the flow is 1 cubic foot per second or greater, the most common unit is the cubic foot per second.

The cubic foot per second (c.f.s.) is generally accepted as the standard unit of measurement expressing the rate of flow. Pump manufacturers have always expressed their pump capacities in gallons per minute; therefore, this unit is still used in discussing flow from wells or pumps. Several other units are used to express the rate of flow, but they differ from those defined above only in the time interval. For quick conversion from one unit to another, without calculation, Table 1 and Figure 1 are included. The top scale on Figure 1 is cubic feet per second. To change from cubic feet per second to any other unit, follow the vertical line downward until it intersects the scale of the unit desired. Thus, 5 c.f.s. equals: 2250 g.p.m., 300 cubic feet per minute, 10 acre-feet per day, or 5 acre-inches per hour.

SOME CONVENIENT RELATIONS

Some convenient relations between the units of flow are:

1. 1 cubic foot per second (c.f.s.) = 450 gallons per minute (g.p.m.) (approximate)
   1 cubic foot = 7.5 gallons (approximate)
   60 seconds = 1 minute
   7.5 x 60 = 450 gallons per minute (g.p.m.)

2. 1 cubic foot per second = 1 acre-inch per hour (approximate)
   3600 seconds = 1 hour
   1 c.f.s. = 3600 cubic feet per hour
   1 acre-foot = 43,560 cubic feet
   1 acre-inch = 1/12 x 43,560 = 3630 cubic feet
   Since 3600 = 3630 (approximately)
   Therefore, 1 c.f.s. = 1 acre-inch per hour (approximate)

TABLE 1
Conversion Table of Flow Units

Cubic feet per second	Gallons per minute	Million gallons per day	Miner's Inches: Arizona Calif. Montana Nevada Oregon	Miner's Inches: Idaho Kansas Nebraska New Mex. No. Dak. So. Dak. Utah	Miner's Inches: Colorado	Acre inches per hour	Acre feet per day (24 Hrs.)
1	(use 450) 448.8	0.646	40	50	38.4	0.992	1.983
0.00223	1	0.001440	0.0891	0.1114	0.0856	0.0022	0.00442
1.547	694.4	1	61.89	77.36	59.44	1.535	3.07
0.025	11.25	0.0162	1	1.25	0.960	0.0248	0.0496
0.020	9.00	0.0129	0.89	1	0.768	0.0198	0.0397
0.026	11.69	0.0168	1.042	1.302	1	0.0258	0.0516
1.01	452.42	0.651	40.32	50.40	38.71	1	2.00
.504	226.3	0.3258	20.17	25.21	19.36	0.5	

1. Example: From Table 1. Utah miner's inch equals 0.02 cubic feet per second, equals 9.00 gallons per minute, equals 0.0198 acre inches per hour, and equals 0.0397 acre feet per day (24 hours).

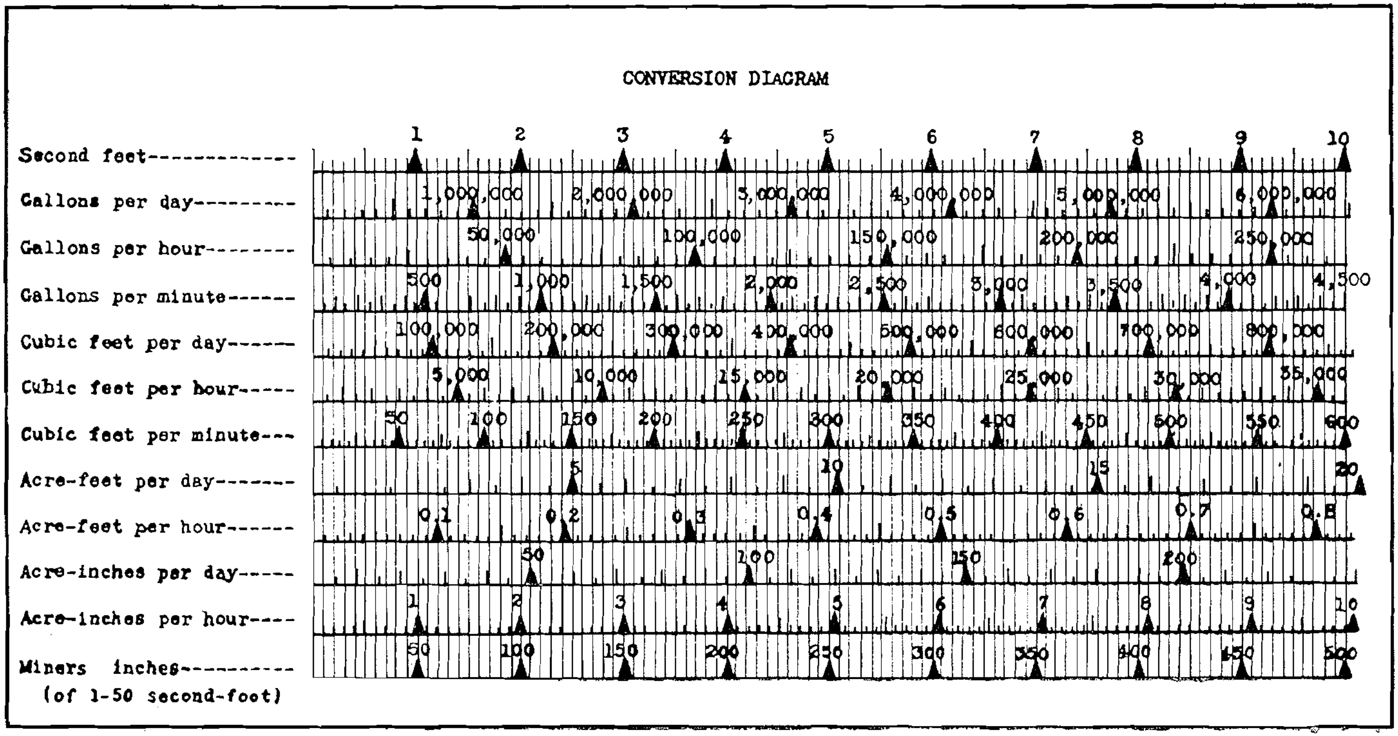

Fig. 1. Conversion diagram for finding equivalent rates of flow.

3. 1 cubic foot per second = 2 acre-feet in 24 hours (approximate)
   1 c.f.s. = 3600 cubic feet per hour
   24 x 3600 = 86,400 cubic feet per 24-hour day
   1 acre-foot = 43,560 cubic feet; 86,400 ÷ 43,560 = 1.9834
   Therefore, 1 c.f.s. = 2 acre feet in 24 hours (approximate)

The following approximate formulas are useful to compute the depth of water to be applied to an area of ground:

1. $\frac{\text{cubic feet per second (c.f.s.)} \times \text{time (hours)}}{\text{Area (acres)}}$ = acre inches per acre or average depth in inches.

2. $\frac{\text{Gallons per minute (g.p.m.)} \times \text{time (hours)}}{450 \times \text{Area (acres)}}$ = acre inches per acre or average depth in inches.

3. $\frac{\text{Miner's inches (Utah)} \times \text{time (hours)}}{50 \times \text{Area (acres)}}$ = acre inches per acre or average depth in inches.

4. $\frac{\text{Miner's inches (Calif. statute)} \times \text{time (hours)}}{40 \times \text{Area (acres)}}$ = acre inches per acre or average depth in inches.

Examples in the Use of Convenient Relations

Examples of how to use the relations given (See Figure 1) are:

1. Jones has a pump which discharges 450 g.p.m. If he spends 60 hours in irrigating a 10-acre orchard, what average depth in inches does he apply? (Note that the size of the stream, the length of time it is to be applied, and the area are given.)
   450 g.p.m. = 1 c.f.s.
   1 c.f.s. for 1 hour = 1 acre-inch
   1 c.f.s. for 60 hours = 60 acre-inches

   Therefore 60 acre-inches are spread uniformly over 10 acres.

   The average depth is 6 inches. (answer)

Applying general formula 2, $\frac{\text{g.p.m.} \times \text{time (in hrs.)}}{450 \times \text{Area (acres)}}$ = Depth in inches

$\frac{450 \times 60}{450 \times 10}$ = 6 inches' depth of application (answer).

Or to solve the same problem graphically by using Figure 2: from table of equivalents, Table 1, 450 g.p.m. = 1 c.f.s. Enter diagram base line time in days at 2½ days (60 hours) following line vertically up to intersection of diagonal line labelled 1.0 c.f.s.; move horizontally to right to intersection of vertical line through area (10 acres); read depth of application from intercepted diagonal line (6 inches).

2. How long will it take to apply a 6-inch irrigation to a 15-acre tract if the size of the irrigation stream is 3 c.f.s?
   $15 \times 6 = 90$ acre-inches to be applied.
   3 c.f.s = 3 acre-inches per hour
   $90/3 = 30$ hours (answer)

3. How much land will a continuous flow of 15 c.f.s. cover in 4 months if each acre must have an average depth of 3 feet?
   1 c.f.s. = 2 acre-feet per day
   15 c.f.s. = 30 acre-feet per day
   $120 \times 30 = 3600$ acre-feet

Each acre requires 3 acre-feet. Total area $= \frac{3600}{3} = 1200$ acres. (answer)

4. A flow of 5 c.f.s. is equal to how many acre-inches per day? (See Figure 1.) Look vertically under 5 c.f.s. and read on the scale of acre-inches per day 120 acre-inches. (answer)

Sample problem drawn on Figure 2:

Example: Given: Irrigation stream (Q) = 1 c.f.s.
Turn, Time in days (T) = 1 day (24 hrs.)
Area to be irrigated in acres (A) = 4 Ac.

Required: Depth of application in inches = 6 inches
Solution, follow dotted line

METHODS OF WATER MEASUREMENT

Several devices are commonly used for measuring irrigation water. Those devices most commonly used in Utah and other parts of the West by engineers, farmers and ditch riders are: weirs, orifices, Parshall flumes, calibrated gates and rating flumes. In addition to the foregoing devices, current meters, Clausen-Pierce Weir gauges, and "Slope area" methods are used by engineers and others who are technically trained. Various mechanical devices for measuring flow have been designed, some of which not only measure rate of flow but also register the total volume of water passing during any period of time.

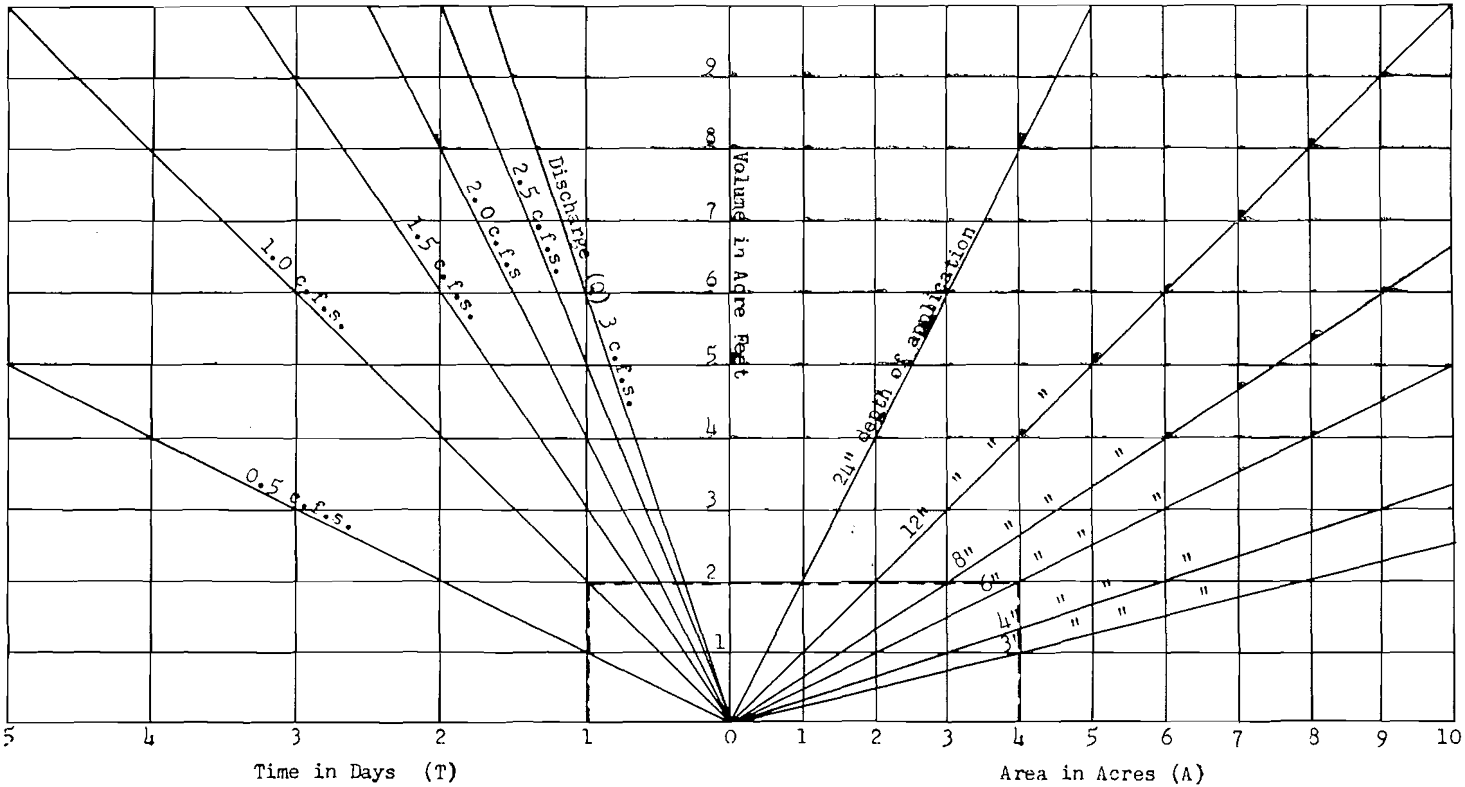

Figure 2. TIME APPLICATION DIAGRAM

CURRENT METERS

The discharge of a stream can be determined directly by measuring the velocity and the cross-sectional area of the water. The most reliable method of determining the velocity of the water is by the use of a current meter, of which several types are available.

Most current meters consist of a wheel fitted with cupped vanes; it is mounted on an axis about which it is free to turn under the action of the stream. This wheel is on the upstream end of a horizontal shaft that has its other end fitted with directional vanes that steady the meter and keep it headed into the current. The meter may be used in shallow water where wading is possible by being supported by a vertical rod held in the hands of the observer. In deeper water the rod is removed and a cable attached to the meter which is suspended from a boat or bridge. To the lower side of the meter is attached a streamlined lead weight which steadies the meter and holds it in position. The wheel revolves at a rate proportional to the velocity of the current in which it is placed. With the meter immersed the revolutions of the wheel are counted by means of an electric circuit which is broken at each revolution by means of a commutator attached to the wheel shaft. The wires of the circuit pass from the meter to the surface where a small buzzer or earphone records the "make" and "break" of the circuit. Current is furnished by a small dry cell battery.

The discharge of a stream is the product of its cross-sectional area and the mean velocity of the water passing a given section. A meter measurement consists of determining with all possible accuracy the value of these two factors. The area for any stage of flow may be easily determined by soundings made across the selected section, the distance of each point of sounding being measured from a permanent point on the bank and in the line of the cross-section. Best results are obtained from gaugings if the area is subdivided into a series of vertical strips, preferably of equal width, and the discharge Q past the entire section is computed on the basis that the symbols a_1, a_2, a_3, etc. being the areas of the respective strips; and v_1, v_2, v_3, etc. the mean velocity for each strip; then, the

$$\text{Total } Q = a_1 v_1 + a_2 v_2 + a_3 v_3 + a_4 v_4 + \text{etc. (See Figure 3.)}$$

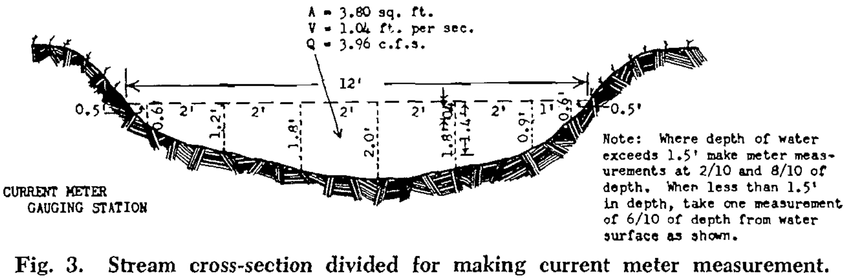

Fig. 3. Stream cross-section divided for making current meter measurement.

9–275
September 1943

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
WATER RESOURCES BRANCH

Name R. A. Cox
Ght. 1.35 @ 9:45 AM
Ght. 1.36 @ 10:45 AM
Mn. Ght. 1.355

Date June 12, 1948 **DISCHARGE MEASUREMENT NOTES** Ft. above, below

Beaver Creek ~~River at~~ at Western Meter

Angle coefficient	Dist. from initial point	Depth	Observation depth	Revolutions	Time in seconds	Velocity: At point	Velocity: Mean in vertical	Velocity: Mean in section	Area	Mean depth	Width	Discharge
	0					0	0	0				
								0.29	0.15	0.3	0.5	0.04
	.5	0.6	0.4	12	56	0.58	0.58					
								0.71	1.8	0.9	2.0	1.28
	2.5	1.2	0.7	15	56	0.84	0.84					
								0.88	3.0	1.5	2.0	2.64
	4.5	1.8	0.36	22	57	1.01	0.95					
			1.44	20	58	.84						
								1.04	3.8	1.9	2.0	3.96
	6.5	2.0	0.4	25	64	1.17	1.12					
			1.6	23	59	1.07						
								1.04	3.8	1.9	2.0	3.96
	8.5	1.8	0.36	22	57	1.01	0.95					
			1.44	20	58	.84						
								0.79	2.8	1.4	2.0	2.21
	10.5	.9	0.56	14	61	0.63	0.63					
								0.57	1.5	0.75	1.0	0.86
	11.5	.6	0.36	11	62	0.51	0.51					
								0.26	0.84	0.42	0.5	0.22
	12.0	0.0	0	0	0	0	0					
												15.17

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Fig. 4. A sample set of stream gauging notes prepared to illustrate form of recording measurements.

A typical set of discharge notes and computations of discharge is shown in Figure 4.

To obtain the value of v it is commonly assumed that the sum of the mean velocities in the vertical, at each end of the strip, divided by 2 may be taken as the mean velocity for the entire strip. Various methods are used for obtaining the mean velocity in the vertical but the most common methods used for relatively small streams are the two-tenths and eight-tenths method and the six-tenths method.

The two-tenths and eight-tenths method consists of determining the velocities at 2/10 and 8/10 the depth and assuming that the mean velocity in the vertical is equal to their arithmetical mean.

The six-tenths method consists of making one measurement in each vertical at 6/10 the depth measured from surface down and assuming the velocity as found at that point to be the true mean.

FLOAT MEASUREMENTS

For a rough estimate of the water flowing in a straight uniform channel, some object such as a piece of wood or an apple may be thrown into the stream and the time required by the object to go a known distance downstream noted. The average cross-sectional area of the water in this length in square feet multiplied by the surface velocity in feet per second, as determined by timing the float, gives a figure which, if multiplied by a coefficient to correct for the fact that the surface velocity of the water is greater than the average velocity, will give the approximate discharge for the stream. Although it varies widely, depending upon the shape of the cross-section and the condition of the banks and bottom of the channel, the average coefficient is about 0.85. The discharge therefore equals approximately 85 per cent of the product of the cross-sectional area times the surface velocity.

The float method of measuring the flow is not recommended except in rare cases where other more reliable means are not available.

WEIRS

When conditions are favorable the weir is one of the simplest, cheapest, and most reliable devices for measuring the flow of water.

Terms Used—The following terms are used in connection with weirs:

Weir—A bulkhead placed across a ditch or stream with an opening cut in the top through which the water is allowed to pass. The opening is called the weir notch.

Weir Pond—The portion of the ditch immediately upstream from the weir.

Weir Crest—The bottom of the weir notch.

Head-on-Crest—The depth of water flowing over the weir crest measured at some point in the weir pond.

Sharp-crested-Weir—A weir having thin-edged crest and sides such that the overflowing water touches the crest at only one point.

End Contraction—The horizontal distance from the end of the weir crest to the side of weir pond.

Bottom Contraction—The vertical distance from the weir crest to the bottom of the weir pond.

Weir Scale or Gauge—The scale fastened on side of weir or on stake in weir pond to measure head-on-crest.

Weirs may be divided into two general classes: (1) sharp-crested and (2) broad-crested. The sharp-crested may again be divided into weirs with end contractions and weirs without end contractions. Only the sharp-crested-weir is discussed in this bulletin.

Weirs may be built as stationary structures or they may be made portable. The portable weirs are usually made of wood or sheet steel and are placed in the ditch where a measurement is desired. The stationary structures may be built of wood, steel, or concrete. In the wood and concrete structures the notch is usually faced with a metal strip which constitutes the sharp crest. Figure 5 shows the use of angle iron for the crest of a concrete weir.

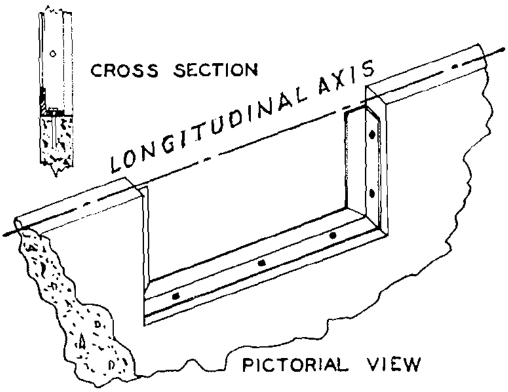

Fig. 5. Angle iron crest in rectangular weir.

The discharge through a weir notch is proportional to the head on the crest and is affected by the condition of the crest, the contraction, the velocity of approach, and the elevation of the water surface down stream from the weir. Each type of weir has its own discharge formula, tables or curves. Therefore, in order to properly measure water with a weir, it should be constructed and installed in a manner similar to that for which the formula, tables and curves were developed. The following are some general requirements for the proper setting and operation of weirs:

(1) The weir should be set at the lower end of a pool sufficiently long, wide and deep to give an even, smooth current with a velocity of approach of not over 0.5 ft. per second, which means practically still water.

(2) The Longitudinal Axis of the weir should be perpendicular to the direction of the flow. If a weir box is used, the centerline of the weir box should be parallel with the direction of flow.

(3) The face of the weir should be vertical, leaning neither upstream nor downstream and at right angles to the direction of flow.

(4) The crest of the weir should be horizontal so that the water passing over it will be the same depth at all points along the crest and sharp-crested so that the overfalling water touches the crest at only one point.

(5) The distance of the crest above the bottom of the pool should be about three times the depth of water flowing over the weir crest. The sides of the pool should be at a distance from the sides of the crest not less than twice the depth of the water passing over the crest.

(6) The gauge or weir scale may be placed on a stake at any point in the weir pond or box provided it is sufficiently above or to one side of the weir to be free from the downward curve of the water surface as it passes over the weir crest (Figure 6); or the weir scale may be placed on the upstream face of the weir structure and far enough to one side so that it will be in comparatively still water, as shown in Figure 7. The zero of the weir scale or gauge must be placed at the same elevation as the weir crest. This may be done with an ordinary carpenter's level or, where greater refinement is desired, with an engineer's level.

(7) The measurement of the head or depth of water on the crest may also be made by placing a carpenter's rule or scale on a lug to the side of the weir notch or on a stake placed in the weir pond 4 or 5 feet above the weir. The lug or stake must be placed level with the weir crest.

(8) The crest should be placed high enough so that the water will fall freely below the weir, leaving an air space under the overfalling sheet of water. If the water below the weir rises above the crest elevation, free fall is not possible and the weir is then said to be submerged. Unless complicated corrections are made, measurements on submerged weirs are unreliable.

(9) For more reliable measurements the depth of water flowing over the crest should be no more than one-third the length of the crest.

(10) The depth of water over the crest should not be less than 2 inches. With smaller depths the over-falling sheet of water tends to cling to the downstream side of the crest and the relationship between the depth of water on the crest and the discharge no longer holds true.

(11) To prevent erosion below the weir, the ditch downstream should be protected by loose rock or by other material.

Limitations in Use of Weirs—Although weirs are easy to construct and convenient to use, they are not suitable for measuring water under all conditions. One of the major disadvantages in the use of weirs is that they require a considerable loss of head which may not be available on ditches with a flat grade. Also, reducing the velocity of the water in the weir pond causes deposition of silt from those streams carrying a heavy silt load and these deposits in the channel of approach destroy the proper conditions for weir measurements. Weirs should not be combined with head gate structures.

Weir Structure—The weir structure may be either portable or stationary. Because of having less bulk, metal weirs are more satisfactory than wooden weirs for portable use. A very substantial metal weir can be made of ⅛ inch (12 gauge) galvanized iron stiffened by means of heavy angles welded together and riveted to the downstream side of the plate. It can then be

Fig. 6

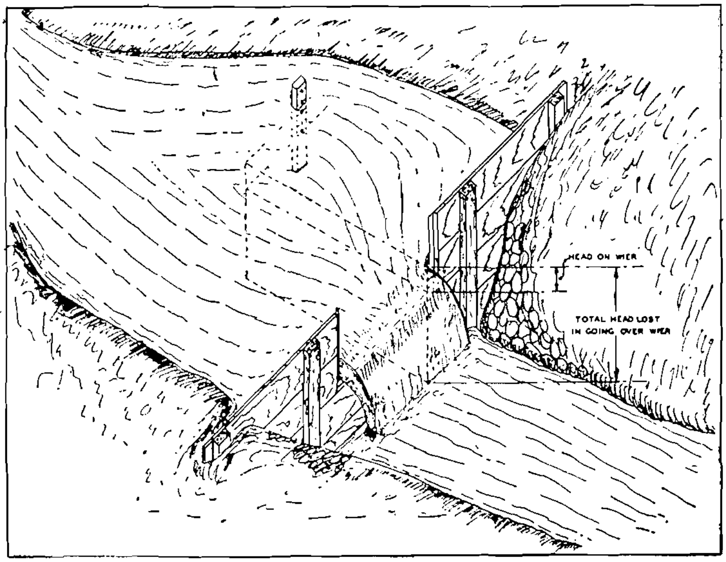

Fig. 6. Weir notch and bulkhead in weir pond.

driven into position in a flowing stream with a heavy wooden block or mallet without shutting the water out of the ditch.

For stationary purposes the type of soil will largely determine whether a simple weir bulkhead and weir pond may be used or a weir box should be built. In the heavy clay soils, where little washing occurs, a simple bulkhead can be used to an advantage, but in light soils, subject to erosion, a weir box with wing walls and cut off walls should be used to prevent the structure from being washed out.

Figure 6 is a drawing of a simple weir bulkhead which can be constructed easily on the farm. With this type of weir the head is usually measured from a stake in the weir pond set at the same elevation as the crest.

Don'ts in Regard to Weirs—For further emphasis on proper use of weirs, the following "don'ts" are included:

1. Don't set weir immediately below a curve in the ditch as the curve will cause the water to flow to the side of the crest.
2. Don't set it immediately below or too close to a headgate, where the water has a high velocity, as too high a velocity of approach will result.
3. Don't allow the water below the weir to back up to the elevation of the crest as it will not allow complete contraction and it will cut down the discharge.
4. Don't set the weir any other way than vertical (plumb) and at right angles to the flow of the stream.

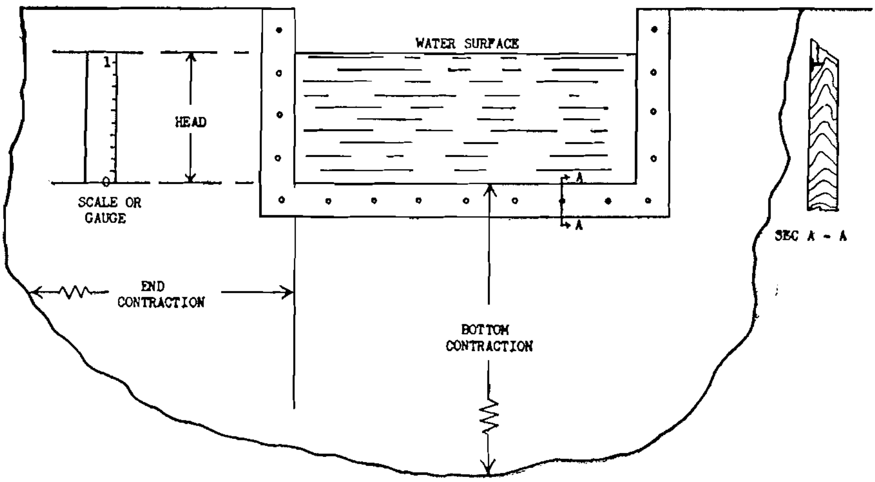

Fig. 7. Rectangular weir with end contractions.

5. Don't attempt to use too small a weir. Put in a larger weir where the water to be measured exceeds a depth on the crest of one-third the crest length.
6. Don't allow the pool above the weir to fill up with sediment as the the resulting decrease in the cross-section will increase the velocity of approach.

Making a Discharge Measurement With a Weir—When the weir is properly installed and the flow through the notch has become steady, measuring the depth of water over the crest of the weir is made by placing a carpenter's rule on the stake or lug which has been fixed at the elevation of the crest or by reading the weir scale. With the head determined, consult the proper discharge curve or table for the weir being used. The curves are so constructed that the head may be measured either in feet or in inches and with the crest lengths varying from 6 inches to 4 feet. For example, suppose that the head on the crest of a 2-foot rectangular weir measured 8.5 inches. From Figure 8, it is seen by following horizontally across the line for a head of 0.7 feet to where it intersects the curve for the 2-foot weir and dropping vertically down that the discharge is 3.7 c.f.s.

To solve the same example using Table 3, enter table with value of head 0.70 feet in left column, "Head, in feet," follow line horizontally to the right and read result under column "Crest length 2.0 feet," 3.71 c.f.s.

Rectangular Weir—The rectangular weir, Figure 7, is named from the shape of its notch. It is the oldest form of weir used. Its simplicity, easy construction and accuracy, when properly installed and used, make it still the most popular weir. Table 2 gives the recommended size of rectangular weirs to use with various size streams of water. The maximum and minimum discharge for the various sizes of weirs overlap considerably or indicate that a weir having a crest length of 3 feet measures a 9-second foot stream with the same accuracy as a 4-foot weir.

By using Figure 8 (p. 23), the discharge for weirs having crest lengths from 6 inches to 4 feet can be determined quickly. To clarify the relationship between head and discharge, and for those who prefer tables in determining discharge, Table 3 is included (pp. 24-26). This table can verify the results obtained from curves and shows the discharge for weir crests of 1.0, 1.5, 2.0, 3.0, and 4.0 feet for heads from 0.1 feet to 1.5 feet.

TABLE 2—Recommended sizes of rectangular weirs.

Flow c. f. s.	Maximum Head Feet	Crest length Feet
0.30 to 2.00	0.75	1.0
2.00 to 2.00	0.75	1.5
2.50 to 6.00	1.00	2.0
5.00 to 13.00	1.25	3.0
8.00 to 20.00	1.40	4.0

FIG. 8

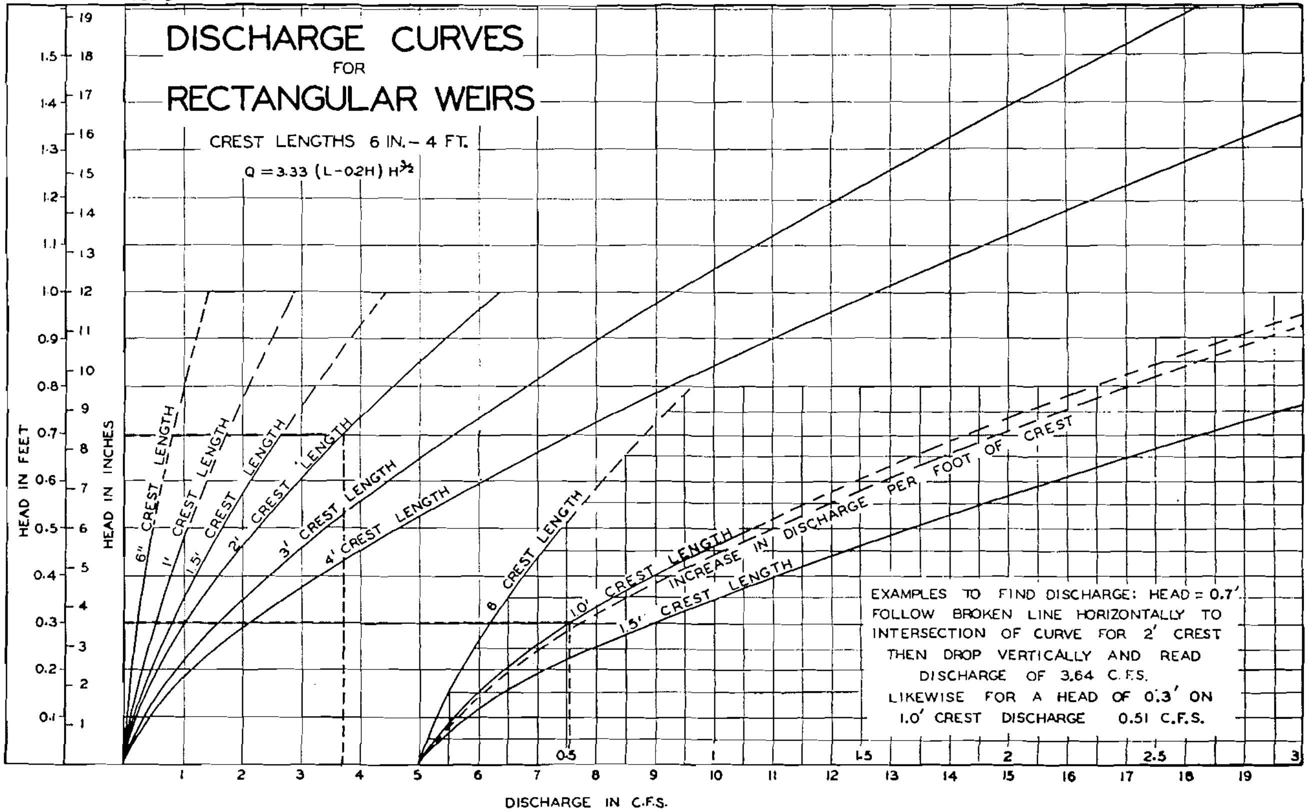

Fig. 8. Discharge curves for rectangular weirs.

TABLE 3

Flow Over Rectangular Contracted Weirs in Cubic Feet Per Second*

Head, in feet	Head, in inches (approx.)	Crest length					For each additional foot of crest in excess of 4 ft. (approx.)
		1.0 foot	1.5 feet	2.0 feet	3.0 feet	4.0 feet	
		Flow in cubic feet per second					
0.10	1 3/16	0.105	0.158	0.212	0.319	0.427	0.108
0.11	1 5/16	0.121	0.182	0.244	0.367	0.491	0.124
0.12	1 7/16	0.137	0.207	0.277	0.418	0.559	0.141
0.13	1 9/16	0.155	0.233	0.312	0.470	0.629	0.159
0.14	1 11/16	0.172	0.260	0.348	0.524	0.701	0.177
0.15	1 13/16	0.191	0.288	0.385	0.581	0.776	0.196
0.16	1 15/16	0.210	0.316	0.423	0.638	0.854	0.216
0.17	2 1/16	0.229	0.346	0.463	0.698	0.934	0.236
0.18	2 3/16	0.249	0.376	0.504	0.760	1.02	0.257
0.19	2¼	0.270	0.407	0.546	0.823	1.10	0.278
0.20	2⅜	0.291	0.439	0.588	0.887	1.19	0.303
0.21	2½	0.312	0.472	0.632	0.954	1.28	0.326
0.22	2⅝	0.335	0.505	0.677	1.02	1.37	0.35
0.23	2¾	0.358	0.539	0.723	1.09	1.46	0.37
0.24	2⅞	0.380	0.574	0.769	1.16	1.55	0.39
0.25	3	0.404	0.609	0.817	1.23	1.65	0.42
0.26	3⅛	0.428	0.646	0.865	1.31	1.75	0.44
0.27	3¼	0.452	0.682	0.914	1.38	1.85	0.47
0.28	3⅜	0.477	0.720	0.965	1.46	1.95	0.49
0.29	3½	0.502	0.758	1.02	1.53	2.05	0.52
0.30	3⅝	0.527	0.796	1.07	1.61	2.16	0.55
0.31	3¾	0.553	0.836	1.12	1.69	2.26	0.57
0.32	3 13/16	0.580	0.876	1.18	1.77	2.37	0.60
0.33	3 15/16	0.606	0.916	1.23	1.86	2.48	0.62
0.34	4 1/16	0.634	0.957	1.28	1.94	2.60	0.66
0.35	4 3/16	0.661	0.999	1.34	2.02	2.71	0.69
0.36	4 5/16	0.688	1.04	1.40	2.11	2.82	0.71
0.37	4 7/16	0.717	1.08	1.45	2.20	2.94	0.74
0.38	4 9/16	0.745	1.13	1.51	2.28	3.06	0.78
0.39	4 11/16	0.774	1.17	1.57	2.37	3.18	0.81
0.40	4 13/16	0.804	1.21	1.63	2.46	3.30	0.84
0.41	4 15/16	0.833	1.26	1.69	2.55	3.42	0.87
0.42	5 1/16	0.863	1.30	1.75	2.65	3.54	0.89
0.43	5 3/16	0.893	1.35	1.81	2.74	3.67	0.93
0.44	5¼	0.924	1.40	1.88	2.83	3.80	0.97
0.45	5⅜	0.955	1.44	1.94	2.93	3.93	1.00
0.46	5½	0.986	1.49	2.00	3.03	4.05	1.02
0.47	5⅝	1.02	1.54	2.07	3.12	4.18	1.06
0.48	5¾	1.05	1.59	2.13	3.22	4.32	1.10
0.49	5⅞	1.08	1.64	2.20	3.32	4.45	1.13
0.50	6	1.11	1.68	2.26	3.42	4.58	1.16
0.51	6⅛	1.15	1.73	2.33	3.52	4.72	1.20
0.52	6¼	1.18	1.78	2.40	3.62	4.86	1.24
0.53	6⅜	1.21	1.84	2.46	3.73	4.99	1.26
0.54	6½	1.25	1.89	2.53	3.83	5.13	1.30

*Computed from Cone's formula: $Q = 3.247\,L\,H^{1.48} - \frac{0.566\,L^{1.8}}{1 + 2\,L^{1.8}}\,H^{1.9}$

TABLE 3—(Continued)

Head, in feet	Head, in inches (approx.)	Crest length 1.0 foot	1.5 feet	2.0 feet	3.0 feet	4.0 feet	For each additional foot of crest in excess of 4 ft. (approx.)
		Flow in cubic feet per second					
0.55	6⅝	1.28	1.94	2.60	3.94	5.27	1.33
0.56	6¾	1.31	1.99	2.67	4.04	5.42	1.38
0.57	6 13/16	1.35	2.04	2.74	4.15	5.56	1.41
5.58	6 15/16	1.38	2.09	2.81	4.26	5.70	1.44
0.59	7 1/16	1.42	2.15	2.88	4.36	5.85	1.49
0.60	7 3/16	1.45	2.20	2.96	4.47	6.00	1.53
0.61	7 5/16	1.49	2.25	3.03	4.59	6.14	1.55
0.62	7 7/16	1.52	2.31	3.10	4.69	6.29	1.60
0.63	7 9/16	1.56	2.36	3.17	4.81	6.44	1.63
0.64	7 11/16	1.60	2.42	3.25	4.92	6.59	1.67
0.65	7 13/16	1.63	2.47	3.32	5.03	6.75	1.72
0.66	7 15/16	1.67	2.53	3.40	5.15	6.90	1.75
0.67	8 1/16	1.71	2.59	3.47	5.26	7.05	1.79
0.68	8 3/16	1.74	2.64	3.56	5.38	7.21	1.83
0.69	8¼	1.78	2.70	3.63	5.49	7.36	1.87
0.70	8⅜	1.82	2.76	3.71	5.61	7.52	1.91
0.71	8½	1.86	2.81	3.78	5.73	7.68	1.95
0.72	8⅝	1.90	2.87	3.86	5.85	7.84	1.99
0.73	8¾	1.93	2.93	3.94	5.97	8.00	2.03
0.74	8⅞	1.97	2.99	4.02	6.09	8.17	2.08
0.75	9	2.01	3.05	4.10	6.21	8.33	2.12
0.76	9⅛	2.05	3.11	4.18	6.33	8.49	2.16
0.77	9¼	2.09	3.17	4.26	6.45	8.66	2.21
0.78	9⅜	2.13	3.23	4.34	6.58	8.82	2.24
0.79	9½	2.17	3.29	4.42	6.70	8.99	2.29
0.80	9⅝	2.21	3.35	4.51	6.83	9.16	2.33
0.81	9¾	2.25	3.41	4.59	6.95	9.33	2.38
0.82	9 13/16	2.29	3.47	4.67	7.08	9.50	2.42
0.83	9 15/16	2.33	3.54	4.75	7.21	9.67	2.46
0.84	10 1/16	2.37	3.60	4.84	7.33	9.84	2.51
0.85	10 3/16	2.41	3.66	4.92	7.46	10.01	2.55
0.86	10 5/16	2.46	3.72	5.01	7.59	10.19	2.60
0.87	10 7/16	2.50	3.79	5.10	7.72	10.36	2.64
0.88	10 9/16	2.54	3.85	5.18	7.85	10.54	2.69
0.89	10 11/16	2.58	3.92	5.27	7.99	10.71	2.72
0.90	10 13/16	2.62	3.98	5.35	8.12	10.89	2.77
0.91	10 15/16	2.67	4.05	5.44	8.25	11.07	2.82
0.92	11 1/16	2.71	4.11	5.53	8.38	11.25	2.87
0.93	11 3/16	2.75	4.18	5.62	8.52	11.43	2.91
0.94	11¼	2.79	4.24	5.71	8.65	11.61	2.96
0.95	11⅜	2.84	4.31	5.80	8.79	11.79	3.00
0.96	11½	2.88	4.37	5.89	8.93	11.98	3.05
0.97	11⅝	2.93	4.44	5.98	9.06	12.16	3.10
0.98	11¾	2.97	4.51	6.07	9.20	12.34	3.14
0.99	11⅞	3.01	4.57	6.15	9.34	12.53	3.19
1.00	12	3.06	4.64	6.25	9.48	12.72	3.24
1.01	12⅛	......	4.71	6.34	9.62	12.91	3.29
1.02	12¼	......	4.78	6.43	9.76	13.10	3.34
1.03	12⅜	......	4.85	6.52	9.90	13.28	3.38
1.04	12½	......	4.92	6.62	10.04	13.47	3.43

TABLE 3—(Continued)

Head, in feet	Head, in inches (approx.)	Crest length					For each additional foot of crest in excess of 4 ft. (approx.)
		1.0 foot	1.5 feet	2.0 feet	3.0 feet	4.0 feet	
		Flow in cubic feet per second					
1.05	12⅝	......	4.98	6.71	10.18	13.66	3.48
1.06	12¾	......	5.05	6.80	10.32	13.85	3.53
1.07	12 13/16	......	5.12	6.90	10.46	14.04	3.58
1.08	12 15/16	......	5.20	6.99	10.61	14.24	3.63
1.09	13 1/16	......	5.26	7.09	10.75	14.43	3.68
1.10	13 3/16	......	5.34	7.19	10.90	14.64	3.74
1.11	13 5/16	......	5.41	7.28	11.04	14.83	3.79
1.12	13 7/16	......	5.48	7.38	11.19	15.03	3.84
1.13	13 9/16	......	5.55	7.47	11.34	15.22	3.88
1.14	13 11/16	......	5.62	7.57	11.48	15.42	3.94
1.15	13 13/16	......	5.69	7.66	11.64	15.62	3.98
1.16	13 15/16	......	5.77	7.76	11.79	15.82	4.03
1.17	14 1/16	......	5.84	7.86	11.94	16.02	4.08
1.18	14 3/16	......	5.91	7.96	12.09	16.23	4.14
1.19	14¼	......	5.98	8.06	12.24	16.43	4.19
1.20	14⅜	......	6.06	8.16	12.39	16.63	4.24
1.21	14½	......	6.13	8.26	12.54	16.83	4.29
1.22	14⅝	......	6.20	8.35	12.69	17.03	4.34
1.23	14¾	......	6.28	8.46	12.85	17.25	4.40
1.24	14⅞	......	6.35	8.56	12.99	17.45	4.46
1.25	15	......	6.43	8.66	13.14	17.65	4.51
1.26	15⅛	......	......	......	13.30	17.87	4.57
1.27	15¼	......	......	......	13.45	18.07	4.62
1.28	15⅜	......	......	......	13.61	18.28	4.67
1.29	15½	......	......	......	13.77	18.50	4.73
1.30	15⅝	......	......	......	13.93	18.71	4.78
1.31	15¾	......	......	......	14.09	18.92	4.82
1.32	15 13/16	......	......	......	14.24	19.12	4.88
1.33	15 15/16	......	......	......	14.40	19.34	4.94
1.34	16 1/16	......	......	......	14.56	19.55	4.99
1.35	16 3/16	......	......	......	14.72	19.77	5.05
1.36	16 5/16	......	......	......	14.88	19.98	5.10
1.37	16 7/16	......	......	......	15.04	20.20	5.16
1.38	16 9/16	......	......	......	15.20	20.42	5.22
1.39	16 11/16	......	......	......	15.36	20.64	5.28
1.40	16 13/16	......	......	......	15.53	20.86	5.33
1.41	16 15/16	......	......	......	15.69	21.08	5.39
1.42	17 1/16	......	......	......	15.85	21.29	5.44
1.43	17 3/16	......	......	......	16.02	21.52	5.50
1.44	17¼	......	......	......	16.19	21.74	5.55
1.45	17⅜	......	......	......	16.34	21.96	5.62
1.46	17½	......	......	......	16.51	22.18	5.67
1.47	17⅝	......	......	......	16.68	22.41	5.73
1.48	17¾	......	......	......	16.85	22.64	5.79
1.49	17⅞	......	......	......	17.01	22.85	5.84
1.50	18	......	......	......	17.17	23.08	5.91

Trapezoidal or Cipolletti Weir—The trapezoidal or the Cipolletti weir, named for the Italian engineer who designed it, is used extensively in irrigation work in the Western United States. It gives equally accurate measurements but is more difficult to construct than the rectangular weir. As the name indicates, the notch is of trapezoidal form as shown in Figure 9. The

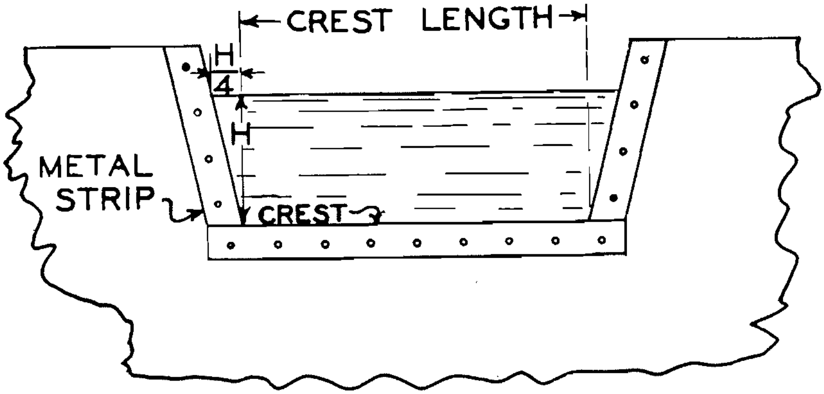

Fig. 9. Trapezoidal or Cipolletti Weir.

side slopes are alike and have an inclination of 1 horizontal to 4 vertical. The discharge may be considered in two parts, one through the rectangular area of the length equal to the crest length, and the other through a triangular area equal to the sum of the area of the two triangles formed at the ends of the rectangle. The total discharge is therefore greater than from a rectangular contracted weir having an equal crest length. Cipolletti proposed giving the sides such a slope that this increase would be just equal to the decrease in discharge through a contracted weir caused by end contractions. Under this condition the discharge is directly proportional to the length of crest; i.e., a Cipolletti weir having a crest length of 4 feet discharges twice as much as one having a crest length of 2 feet. The recommended size of trapezoidal weir to use with various size streams of water is given in Table 5.

It should be noted that the property of equal discharge per unit length of weir crest makes the Cipolletti weir an excellent device for use in division of quantities of water in addition to being a measuring device. See page 71, Dividers.

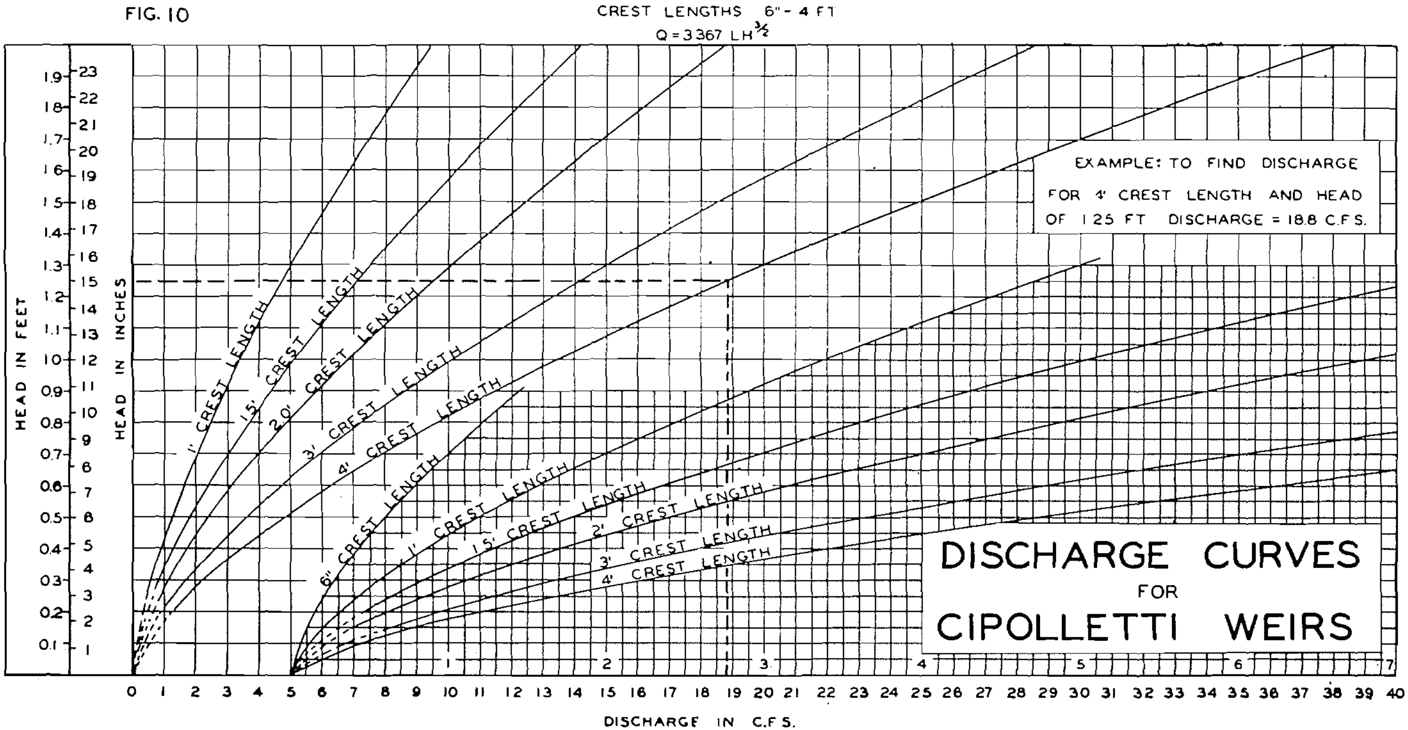

Fig. 10. Discharge curves for Cipolletti weirs.

TABLE 4

Flow Over Cipolletti Weirs in Cubic Feet Per Second*

Head, in feet	Head, in inches (approx.)	Crest length: 1.0 foot	Crest length: 1.5 feet	Crest length: 2.0 feet	Crest length: 3.0 feet	Crest length: 4.0 feet	For each additional foot of crest in excess of 4 ft. (approx.)
		Flow in cubic feet per second					
0.10	1 3/16	0.107	0.160	0.214	0.321	0.429	0.108
0.11	1 5/16	0.123	0.185	0.246	0.370	0.494	0.124
0.12	1 7/16	0.140	0.210	0.280	0.421	0.562	0.141
0.13	1 9/16	0.158	0.237	0.316	0.474	0.632	0.159
0.14	1 11/16	0.177	0.264	0.352	0.528	0.706	0.177
0.15	1 13/16	0.195	0.293	0.390	0.586	0.782	0.196
0.16	1 15/16	0.216	0.322	0.430	0.644	0.860	0.216
0.17	2 1/16	0.237	0.353	0.470	0.705	0.941	0.236
0.18	2 3/16	0.258	0.384	0.512	0.768	1.024	0.257
0.19	2¼	0.280	0.417	0.555	0.832	1.110	0.278
0.20	2⅜	0.302	0.450	0.599	0.898	1.20	0.302
0.21	2½	0.324	0.484	0.644	0.966	1.29	0.324
0.22	2⅝	0.349	0.519	0.691	1.04	1.38	0.35
0.23	2¾	0.374	0.555	0.739	1.11	1.47	0.37
0.24	2⅞	0.397	0.591	0.786	1.18	1.57	0.39
0.25	3	0.423	0.628	0.836	1.25	1.67	0.42
0.26	3⅛	0.449	0.667	0.886	1.33	1.77	0.44
0.27	3¼	0.475	0.705	0.937	1.40	1.87	0.47
0.28	3⅜	0.502	0.745	0.990	1.48	1.97	0.49
0.29	3½	0.529	0.785	1.04	1.56	2.08	0.52
0.30	3⅝	0.557	0.827	1.10	1.64	2.19	0.55
0.31	3¾	0.586	0.869	1.15	1.73	2.30	0.57
0.32	3 13/16	0.615	0.911	1.21	1.81	2.41	0.60
0.33	3 15/16	0.644	0.954	1.27	1.89	2.52	0.62
0.34	4 1/16	0.675	1.00	1.32	1.98	2.64	0.66
0.35	4 3/16	0.705	1.04	1.38	2.07	2.75	0.69
0.36	4 5/16	0.735	1.09	1.44	2.16	2.87	0.71
0.37	4 7/16	0.767	1.13	1.50	2.25	2.99	0.74
0.38	4 9/16	0.799	1.18	1.57	2.34	3.11	0.78
0.39	4 11/16	0.832	1.23	1.63	2.43	3.24	0.81
0.40	4 13/16	0.866	1.28	1.69	2.53	3.36	0.84
0.41	4 15/16	0.899	1.32	1.76	2.62	3.49	0.87
0.42	5 1/16	0.932	1.37	1.82	2.72	3.61	0.89
0.43	5 3/16	0.967	1.42	1.89	2.81	3.74	0.93
0.44	5¼	1.00	1.47	1.95	2.91	3.87	0.97
0.45	5⅜	1.04	1.53	2.02	3.01	4.01	1.00
0.46	5½	1.07	1.58	2.09	3.11	4.14	1.02
0.47	5⅝	1.11	1.63	2.16	3.21	4.28	1.06
0.48	5¾	1.15	1.68	2.23	3.32	4.41	1.10
0.49	5⅞	1.18	1.74	2.30	3.42	4.55	1.13
0.50	6	1.22	1.79	2.37	3.53	4.69	1.16
0.51	6⅛	1.26	1.85	2.44	3.64	4.83	1.20
0.52	6¼	1.30	1.90	2.51	3.74	4.97	1.24
0.53	6⅜	1.34	1.96	2.59	3.85	5.12	1.26
0.54	6½	1.38	2.02	2.66	3.96	5.26	1.30

*Computed from Cone's formula: $Q = 3.247\, L\, H^{1.48} - \frac{0.566\, L^{1.8}}{1 + 2\, L^{1.8}} H^{1.9} + 0.609\, H^{2.5}$

TABLE 4—(Continued)

Head, in feet	Head, in inches (approx.)	Crest length: 1.0 foot	Crest length: 1.5 feet	Crest length: 2.0 feet	Crest length: 3.0 feet	Crest length: 4.0 feet	For each additional foot of crest in excess of 4 ft. (approx.)
		Flow in cubic feet per second					
0.55	6⅝	1.42	2.07	2.74	4.07	5.41	1.33
0.56	6¾	1.46	2.13	2.81	4.18	5.56	1.38
0.57	6 13/16	1.50	2.19	2.89	4.30	5.71	1.41
0.58	6 15/16	1.54	2.25	2.97	4.41	5.86	1.44
0.59	7 1/16	1.58	2.31	3.05	4.53	6.01	1.49
0.60	7 3/16	1.62	2.37	3.13	4.64	6.17	1.53
0.61	7 5/16	1.67	2.43	3.20	4.76	6.32	1.55
0.62	7 7/16	1.71	2.49	3.28	4.88	6.47	1.60
0.63	7 9/16	1.75	2.55	3.37	5.00	6.63	1.63
0.64	7 11/16	1.80	2.62	3.45	5.12	6.79	1.67
0.65	7 13/16	1.84	2.68	3.53	5.24	6.95	1.72
0.66	7 15/16	1.89	2.75	3.61	5.36	7.11	1.75
0.67	8 1/16	1.93	2.81	3.70	5.48	7.28	1.79
0.68	8 3/16	1.98	2.87	3.79	5.61	7.44	1.83
0.69	8¼	2.02	2.94	3.87	5.73	7.61	1.87
0.70	8⅜	2.07	3.01	3.95	5.86	7.77	1.91
0.71	8½	2.12	3.07	4.04	5.99	7.94	1.95
0.72	8⅝	2.16	3.14	4.13	6.12	8.11	1.99
0.73	8¾	2.21	3.21	4.22	6.24	8.28	2.03
0.74	8⅞	2.26	3.28	4.31	6.38	8.45	2.08
0.75	9	2.31	3.35	4.40	6.51	8.62	2.12
0.76	9⅛	2.36	3.42	4.49	6.64	8.80	2.16
0.77	9¼	2.41	3.49	4.58	6.77	8.97	2.21
0.78	9⅜	2.46	3.56	4.67	6.90	9.15	2.24
0.79	9½	2.51	3.63	4.76	7.04	9.33	2.29
0.80	9⅝	2.56	3.70	4.85	7.18	9.51	2.33
0.81	9¾	2.61	3.77	4.95	7.31	9.69	2.38
0.82	9 13/16	2.66	3.84	5.04	7.45	9.87	2.42
0.83	9 15/16	2.71	3.92	5.14	7.59	10.05	2.46
0.84	10 1/16	2.77	3.99	5.23	7.73	10.23	2.51
0.85	10 3/16	2.82	4.07	5.33	7.87	10.42	2.55
0.86	10 5/16	2.87	4.14	5.43	8.01	10.60	2.60
0.87	10 7/16	2.93	4.22	5.52	8.15	10.79	2.64
0.88	10 9/16	2.98	4.29	5.62	8.30	10.98	8.69
0.89	10 11/16	3.04	4.37	5.72	8.44	11.17	2.72
0.90	10 13/16	3.09	4.45	5.82	8.59	11.36	2.77
0.91	10 15/16	3.15	4.53	5.92	8.73	11.55	2.82
0.92	11 1/16	3.20	4.60	6.02	8.88	11.74	2.87
0.93	11 3/16	3.26	4.68	6.13	9.03	11.94	2.91
0.94	11¼	3.32	4.76	6.23	9.17	12.13	2.96
0.95	11⅜	3.37	4.84	6.33	9.32	12.33	3.00
0.96	11½	3.43	4.92	6.44	9.48	12.53	3.05
0.97	11⅝	3.49	5.00	6.55	9.62	12.72	3.10
0.98	11¾	3.55	5.09	6.64	9.78	12.92	3.14
0.99	11⅞	3.61	5.17	6.75	9.93	13.12	3.19
1.00	12	3.67	5.25	6.86	10.08	13.32	3.24
1.01	12⅛	......	5.33	6.96	10.24	13.53	3.29
1.02	12¼	......	5.42	7.07	10.40	13.73	3.34
1.03	12⅜	......	5.50	7.18	10.55	13.94	3.38
1.04	12½	......	5.59	7.29	10.71	14.15	3.43

TABLE 4—(Continued)

Head, in feet	Head, in inches (approx.)	Crest length					For each additional foot of crest in excess of 4 ft. (approx.)
		1.0 foot	1.5 feet	2.0 feet	3.0 feet	4.0 feet	
		Flow in cubic feet per second					
1.05	12⅝	......	5.67	7.40	10.87	14.35	3.48
1.06	12¾	......	5.76	7.51	11.03	14.56	3.53
1.07	12 13/16	......	5.84	7.62	11.18	14.76	3.58
1.08	12 15/16	......	5.93	7.73	11.35	14.98	3.63
1.09	13 1/16	......	6.02	7.84	11.51	15.19	3.68
1.10	13 3/16	......	6.11	7.96	11.68	15.41	3.74
1.11	13 5/16	......	6.20	8.07	11.84	15.62	3.79
1.12	13 7/16	......	6.29	8.18	12.00	15.84	3.84
1.13	13 9/16	......	6.37	8.29	12.16	16.04	3.88
1.14	13 11/16	......	6.46	8.41	12.33	16.26	3.94
1.15	13 13/16	......	6.56	8.53	12.50	16.48	3.98
1.16	13 15/16	......	6.65	8.65	12.67	16.70	4.03
1.17	14 1/16	......	6.74	8.76	12.84	16.93	4.08
1.18	14 3/16	......	6.83	8.88	13.01	17.15	4.14
1.19	14¼	......	6.93	9.00	13.18	17.37	4.19
1.20	14⅜	......	7.02	9.12	13.35	17.59	4.24
1.21	14½	......	7.11	9.24	13.52	17.81	4.29
1.22	14⅝	......	7.20	9.36	13.69	18.03	4.34
1.23	14¾	......	7.30	9.48	13.87	18.27	4.40
1.24	14⅞	......	7.40	9.60	14.04	18.49	4.46
1.25	15	......	7.49	9.72	14.21	18.71	4.51
1.26	15⅛	......	......	......	14.39	18.95	4.57
1.27	15¼	......	......	......	14.56	19.17	4.62
1.28	15⅜	......	......	......	14.74	19.41	4.67
1.29	15½	......	......	......	14.92	19.65	4.73
1.30	15⅝	......	......	......	15.11	19.88	4.78
1.31	15¾	......	......	......	15.29	20.12	4.82
1.32	15 13/16	......	......	......	15.46	20.34	4.88
1.33	15 15/16	......	......	......	15.64	20.58	4.94
1.34	16 1/16	......	......	......	15.82	20.82	4.99
1.35	16 3/16	......	......	......	16.01	21.06	5.05
1.36	16 5/16	......	......	......	16.19	21.29	5.10
1.37	16 7/16	......	......	......	16.37	21.53	5.16
1.38	16 9/16	......	......	......	16.57	21.78	5.22
1.39	16 11/16	......	......	......	16.75	22.02	5.28
1.40	16 13/16	......	......	......	16.94	22.27	5.33
1.41	16 15/16	......	......	......	17.13	22.51	5.39
1.42	17 1/16	......	......	......	17.31	22.75	5.44
1.43	17 3/16	......	......	......	17.51	23.01	5.50
1.44	17¼	......	......	......	17.70	23.26	5.55
1.45	17⅜	......	......	......	17.89	23.50	5.62
1.46	17½	......	......	......	18.08	23.75	5.67
1.47	17⅝	......	......	......	18.28	24.01	5.73
1.48	17¾	......	......	......	18.47	24.26	5.79
1.49	17⅞	......	......	......	18.66	24.50	5.84
1.50	18	......	......	......	18.85	24.75	5.91

TABLE 5—Recommended sizes of Cipolletti weirs.

Flow (c. f. s.)	Maximum Head (Ft.)	Crest length (Ft.)
0.30 to 2.30	0.75	1.0
2.00 to 4.00	0.85	1.5
3.00 to 7.00	1.02	2.0
5.00 to 14.00	1.24	3.0
8.00 to 22.00	1.40	4.0

Discharge curves for Cipolletti weirs having crest lengths from 6 inches to 4 feet are shown in Figure 10. Discharge tables for Cipolletti weirs are included in Table 4.

Ninety-Degree Triangular Notch Weir—The triangular notch weir, Figure 11, is especially adapted to the measurement of small quantities of water varying from a very small fraction of a second-foot to about 2.5 second feet. Its shape makes it easy to construct and install. The 90-degree weir should be so placed that each side makes an angle of 45 degrees or half pitch with

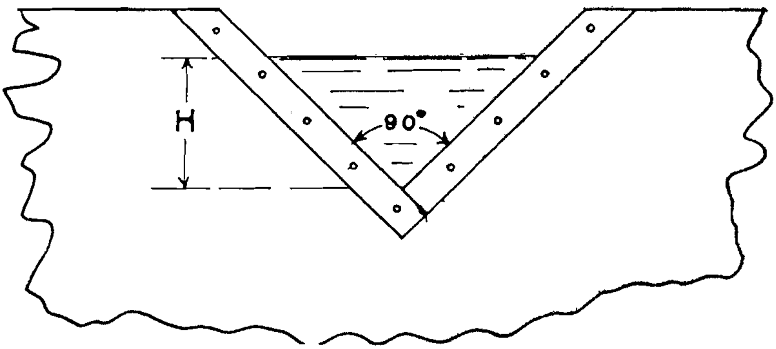

Fig. 11. Ninety-Degree Triangular Notch weir.

the vertical. For a maximum discharge of 2.5 second-feet, the head H is approximately 1 foot. The total necessary difference in elevation of the water surface upstream and downstream from the weir therefore approaches 1½ feet. (See requirement No. 8, page 19).

Discharge curves for the triangular weir are shown in Figure 12. For example, if the depth of water over the vertex or lowest point in the notch is 9 inches, the discharge is 1.22 second feet.

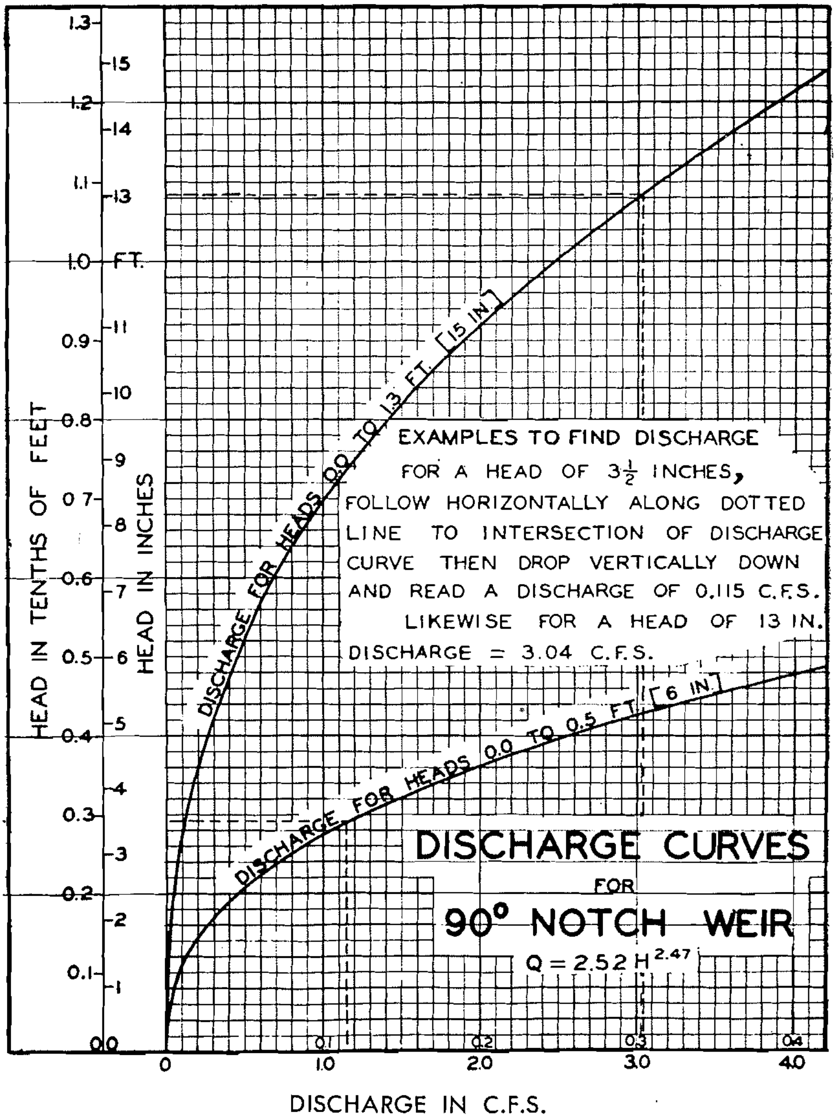

Fig. 12. Dicharge curves for 90° notch weir.

TABLE 6

Flow Over 90-Degree Triangular-Notch Weir in Cubic Feet Per Second and Gallons Per Minute

Head in feet	Head, in inches (approx.)	Flow in cubic feet per second	Flow in gallons per minute
0.10	1 3/16	0.008	3.6
0.11	1 5/16	0.010	4.6
0.12	1 7/16	0.012	5.7
0.13	1 9/16	0.016	6.8
0.14	1 11/16	0.019	8.1
0.15	1 13/16	0.022	9.5
0.16	1 15/16	0.026	11.2
0.17	2 1/16	0.031	13.1
0.18	2 3/16	0.035	15.2
0.19	2¼	0.040	17.5
0.20	2⅜	0.046	19.9
0.21	2½	0.052	22.5
0.22	2⅝	0.058	25.3
0.23	2¾	0.065	28.3
0.24	2⅞	0.072	31.6
0.25	3	0.080	35.1
0.26	3⅛	0.088	38.8
0.27	3¼	0.096	42.8
0.28	3⅜	0.106	47.0
0.29	3½	0.115	51.4
0.30	3⅝	0.125	56.0
0.31	3¾	0.136	60.8
0.32	3 13/16	0.147	65.8
0.33	3 15/16	0.159	71.1
0.34	4 1/16	0.171	76.7
0.35	4 3/16	0.184	82.6
0.36	4 5/16	0.197	88.8
0.37	4 7/16	0.211	95.0
0.38	4 9/16	0.226	101.0
0.39	4 11/16	0.240	108.0
0.40	4 13/16	0.256	115
0.41	4 15/16	0.272	122
0.42	5 1/16	0.289	130
0.43	5 3/16	0.306	137
0.44	5¼	0.324	145
0.45	5⅜	0.343	154
0.46	5½	0.362	162
0.47	5⅝	0.382	171
0.48	5¾	0.403	181
0.49	5⅞	0.424	190
0.50	6	0.445	200
0.51	6⅛	0.468	210
0.52	6¼	0.491	220
0.53	6⅜	0.515	231
0.54	6½	0.539	242

TABLE 6—(Continued)

Head in feet	Head, in inches (approx.)	Flow in cubic feet per second	Flow in gallons per minute
0.55	6⅝	0.564	253
0.56	6¾	0.590	265
0.57	6 13/16	0.617	277
0.58	6 15/16	0.644	289
0.59	7 1/16	0.672	302
0.60	7 3/16	0.700	315
0.61	7 5/16	0.730	328
0.62	7 7/16	0.760	341
0.63	7 9/16	0.790	355
0.64	7 11/16	0.822	369
0.65	7 13/16	0.854	383
0.66	7 15/16	0.887	398
0.67	8 1/16	0.921	413
0.68	8 3/16	0.955	429
0.69	8¼	0.991	445
0.70	8⅜	1.03	461
0.71	8½	1.06	477
0.72	8⅝	1.10	494
0.73	8¾	1.14	512
0.74	8⅞	1.18	530
0.75	9	1.22	548
0.76	9⅛	1.26	566
0.77	9¼	1.30	585
0.78	9⅜	1.34	604
0.79	9½	1.39	624
0.80	9⅝	1.43	644
0.81	9¾	1.48	664
0.82	9 13/16	1.52	684
0.83	9 15/16	1.57	704
0.84	10 1/16	1.61	725
0.85	10 3/16	1.66	746
0.86	10 5/16	1.71	768
0.87	10 7/16	1.76	790
0.88	10 9/16	1.81	812
9.89	10 11/16	1.86	835
0.90	10 13/16	1.92	858
0.91	10 15/16	1.97	882
0.92	11 1/16	2.02	906
0.93	11 3/16	2.08	931
0.94	11¼	2.13	956
0.95	11⅜	2.19	983
0.96	11½	2.25	1,010
0.97	11⅝	2.31	1.040
0.98	11¾	2.37	1,060
0.99	11⅞	2.43	1,090

TABLE 6—(Continued)

Head in feet	Head, in inches (approx.)	Flow in cubic feet per second	Flow in gallons per minute
1.00	12	2.49	1,120
1.01	12⅛	2.55	1,140
1.02	12¼	2.61	1,170
1.03	12⅜	2.68	1,200
1.04	12½	2.74	1,230
1.05	12⅝	2.81	1,260
1.06	12¾	2.87	1,290
1.07	12 13/16	2.94	1,320
1.08	12 15/16	3.01	1,350
1.09	13 1/16	3.08	1,380
1.10	13 3/16	3.15	1,410
1.11	15 5/16	3.22	1,440
1.12	13 7/16	3.30	1,480
1.13	13 9/16	3.37	1,510
1.14	13 11/16	3.44	1,540
1.15	13 13/16	3.52	1,580
1.16	13 15/16	3.59	1,610
1.17	14 1/16	3.67	1,650
1.18	14 3/16	3.75	1,680
1.19	14¼	3.83	1,720
1.20	14⅜	3.91	1,760

RECTANGULAR SUPPRESSED WEIR

The rectangular suppressed weir or weir without end contractions consists of a bulkhead in a rectangular flume section. The bulkhead should be sufficiently high from the bottom of the flume that the distance from the weir crest to the bottom of the flume is at least twice and preferably three times the head of the water expected to flow over the weir. The flume section should be uniform in cross-section, having a horizontal base and vertical side at any cross-section. The bulkhead should be set in a vertical plane, and the upstream face should be smooth with a crest width not in excess of ⅛″ in thickness. The crest of the weir must be horizontal. The head is determined in the same manner as for other weirs. For more accurate results, a stilling well (measuring well) and a hook gauge with vernier are recommended.

The water surface as it falls over the crest of a suppressed weir completely fills the flume, and cuts off the free circulation of air under the overfalling sheet. For the weir to function properly, artificial ventilation should be provided by drilling a small hole in each side wall near the downstream edge and a little below the weir crest.

Discharge curves for the rectangular suppressed weir are shown in Figure 13. For example, if the depth of water flowing over the crest of a 1-foot-high weir (length of weir 1 foot) is 0.75 feet, the discharge from curves is 2.32 c.f.s. This result may be checked by reference to Table 7.

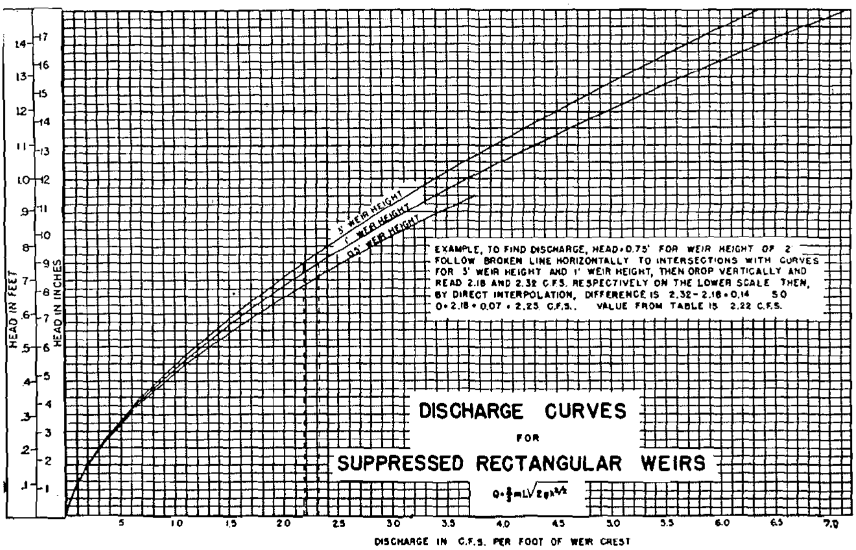

Fig. 13. Discharge curves for suppressed rectangular weirs.

TABLE 7

Flow Over Rectangular Suppressed Weirs in Cubic Feet Per Second*

Head, in feet	Head, in inches (approx.)	Weir height						
		0.5 foot	0.75 foot	1.0 foot	1.5 feet	2.0 feet	3.0 feet	4.0 feet
		Flow in cubic feet per second per foot of weir crest						
0.10	1 3/16	0.111	0.110	0.109	0.109	0.108	0.108	0.108
0.11	1 5/16	0.127	0.126	0.126	0.125	0.125	0.125	0.124
0.12	1 7/16	0.145	0.144	0.143	0.142	0.142	0.141	0.141
0.13	1 9/16	0.163	0.162	0.161	0.160	0.159	0.159	0.159
0.14	1 11/16	0.182	0.180	0.179	0.178	0.178	0.177	0.177
0.15	1 13/16	0.202	0.200	0.199	0.197	0.197	0.196	0.196
0.16	1 15/16	0.223	0.220	0.219	0.217	0.216	0.216	0.215
0.17	2 1/16	0.244	0.241	0.239	0.238	0.237	0.236	0.235
0.18	2 3/16	0.266	0.263	0.261	0.259	0.257	0.257	0.256
0.19	2¼	0.289	0.285	0.283	0.280	0.279	0.277	0.277
0.20	2⅜	0.312	0.307	0.305	0.302	0.300	0.299	0.299
0.21	2½	0.336	0.331	0.328	0.325	0.324	0.322	0.322
0.22	2⅝	0.361	0.355	0.352	0.349	0.347	0.345	0.344
0.23	2¾	0.387	0.386	0.376	0.372	0.370	0.369	0.368
0.24	2⅞	0.413	0.406	0.401	0.397	0.395	0.393	0.392
0.25	3	0.440	0.431	0.427	0.422	0.420	0.418	0.416
0.26	3⅛	0.467	0.458	0.452	0.447	0.445	0.442	0.442
0.27	3¼	0.495	0.485	0.479	0.473	0.471	0.468	0.467
0.28	3⅜	0.524	0.513	0.506	0.500	0.498	0.495	0.493
0.29	3½	0.554	0.541	0.535	0.527	0.524	0.521	0.520
0.30	3⅝	0.583	0.569	0.562	0.555	0.552	0.548	0.545
0.31	3 11/16	0.614	0.559	0.591	0.583	0.580	0.576	0.574
0.32	3 13/16	0.645	0.629	0.620	0.612	0.608	0.604	0.602
0.33	5 15/16	0.677	0.659	0.650	0.641	0.637	0.633	0.631
0.34	4 1/16	0.709	0.690	0.681	0.670	0.666	0.662	0.660
0.35	4 3/16	0.742	0.722	0.711	0.701	0.696	0.691	0.688
0.36	4 5/16	0.775	0.754	0.743	0.731	0.725	0.721	0.717
0.37	4 7/16	0.810	0.787	0.774	0.762	0.757	0.751	0.748
0.38	4 9/16	0.844	0.819	0.807	0.793	0.788	0.782	0.778
0.39	4 11/16	0.881	0.853	0.840	0.826	0.819	0.813	0.809
0.40	4 13/16	0.916	0.888	0.873	0.858	0.851	0.844	0.840
0.41	4 15/16	0.952	0.922	0.907	0.890	0.883	0.876	0.872
0.42	5 1/16	0.990	0.958	0.942	0.924	0.917	0.908	0.904
0.43	5⅛	1.03	0.994	0.976	0.958	0.950	0.941	0.937
0.44	5¼	1.07	1.03	1.01	0.993	0.983	0.974	0.969
0.45	5⅜	1.10	1.07	1.05	1.03	1.02	1.01	1.00
0.46	5½	1.14	1.10	1.08	1.06	1.05	1.04	1.04
0.47	5⅝	1.18	1.14	1.12	1.10	1.09	1.08	1.07
0.48	5¾	1.22	1.18	1.16	1.13	1.12	1.11	1.10
0.48	5⅞	1.27	1.22	1.19	1.17	1.16	1.15	1.14
0.50	6	1.31	1.26	1.23	1.21	1.20	1.18	1.18
0.51	6⅛	1.35	1.30	1.27	1.24	1.23	1.22	1.21
0.52	6¼	1.39	1.34	1.31	1.28	1.27	1.25	1.25
0.53	6⅜	1.44	1.38	1.35	1.32	1.30	1.29	1.28
0.54	6½	1.48	1.42	1.39	1.36	1.34	1.33	1.32

*Computed from the simplified form of Rehbock's formula $Q = 2/3\ m\ L\ \sqrt{2\ g}\ h^{3/2}$, where $m = 0.605 + \frac{0.003}{h} + 0.08 \frac{h}{P}$ and P = height of weir crest above bottom of channel of approach.

TABLE 7—(Continued)

Head, in feet	Head, in inches (approx.)	Weir height						
		0.5 foot	0.75 foot	1.0 foot	1.5 feet	2.0 feet	3.0 feet	4.0 feet
		Flow in cubic feet per second per foot of weir crest						
0.55	6⅝	1.52	1.46	1.43	1.40	1.38	1.36	1.36
0.56	6 11/16	1.57	1.50	1.47	1.44	1.42	1.40	1.39
0.57	6 13/16	1.61	1.54	1.51	1.48	1.46	1.44	1.43
0.58	6 15/16	1.66	1.59	1.55	1.52	1.50	1.48	1.47
0.59	7 1/16	1.71	1.63	1.60	1.56	1.54	1.52	1.51
0.60	7 3/16	1.76	1.68	1.64	1.60	1.58	1.56	1.55
0.61	7 5/16	1.80	1.72	1.68	1.64	1.62	1.59	1.58
0.62	7 7/16	1.85	1.77	1.72	1.68	1.66	1.63	1.62
0.63	7 9/16	1.90	1.81	1.77	1.72	1.70	1.68	1.67
0.64	7 11/16	1.95	1.86	1.81	1.76	1.74	1.72	1.71
0.65	7 13/16	2.00	1.90	1.86	1.81	1.78	1.76	1.75
0.66	7 15/16	2.05	1.95	1.90	1.85	1.82	1.80	1.79
0.67	8 1/16	2.10	2.00	1.95	1.90	1.87	1.84	1.83
0.68	8⅛	2.15	2.05	1.99	1.94	1.91	1.88	1.87
0.69	8¼	2.21	2.09	2.04	1.98	1.95	1.93	1.91
0.70	8⅜	2.26	2.14	2.08	2.03	2.00	1.97	1.95
0.71	8½	2.31	2.19	2.13	2.07	2.04	2.01	2.00
0.72	8⅝	2.37	2.24	2.18	2.12	2.08	2.05	2.04
0.73	8¾	2.42	2.29	2.23	2.16	2.13	2.10	2.08
0.74	8⅞	2.48	2.34	2.28	2.21	2.18	2.14	2.12
0.75	9	2.53	2.39	2.32	2.25	2.22	2.18	2.17
0.76	9⅛	2.59	2.45	2.37	2.30	2.27	2.23	2.21
0.77	9¼	2.65	2.50	2.43	2.35	2.31	2.27	2.26
0.78	9⅜	2.70	2.55	2.48	2.40	2.36	2.32	2.30
0.79	9½	2.76	2.60	2.52	2.45	2.41	2.37	2.35
0.80	9⅝	2.82	2.66	2.58	2.49	2.45	2.41	2.39
0.81	9 11/16	2.88	2.71	2.63	2.54	2.50	2.46	2.44
0.82	9 13/16	2.94	2.76	2.68	2.59	2.55	2.51	2.48
0.83	9 15/16	3.00	2.82	2.73	2.64	2.60	2.55	2.53
0.84	10 1/16	3.06	2.87	2.78	2.69	2.64	2.60	2.58
0.85	10 3/16	3.12	2.93	2.84	2.74	2.69	2.65	2.62
0.86	10 5/16	3.18	2.99	2.89	2.79	2.74	2.69	2.67
0.87	10 7/16	3.25	3.04	2.94	2.84	2.80	2.80	2.72
0.88	10 9/16	3.31	3.10	3.00	2.90	2.84	2.79	2.76
0.89	10 11/16	3.37	3.16	3.05	2.95	2.89	2.84	2.81
0.90	10 13/16	3.43	3.22	3.11	3.00	2.95	2.89	2.86
0.91	10 15/16	3.50	3.27	3.16	3.05	2.99	2.94	2.91
0.92	11 1/16	3.57	3.34	3.22	3.11	3.04	2.99	2.96
0.93	11 3/16	3.63	3.40	3.28	3.16	3.10	3.04	3.01
0.94	11¼	3.70	3.46	3.33	3.21	3.15	3.09	3.06
0.95	11⅜	3.76	3.52	3.39	3.26	3.20	3.14	3.11
0.96	11½	3.83	3.58	3.45	3.32	3.26	3.19	3.16
0.97	11⅝	3.90	3.64	3.51	3.37	3.31	3.24	3.21
0.98	11¾	3.97	3.70	3.57	3.42	3.36	3.29	3.26
0.99	11⅞	4.04	3.76	3.62	3.48	3.41	3.35	3.31
1.00	12	4.11	3.82	3.68	3.54	3.47	3.40	3.36
1.01	12⅛	......	3.89	3.74	3.59	3.52	3.45	3.41
1.02	12¼	......	3.95	3.80	3.65	3.58	3.50	3.47
1.03	12⅜	......	4.01	3.86	3.71	3.63	3.56	3.52
1.04	12½	......	4.08	3.93	3.77	3.69	3.61	3.57

TABLE 7—(Continued)

Head, in feet	Head, in inches (approx.)	Weir height: 0.5 foot	0.75 foot	1.0 foot	1.5 feet	2.0 feet	3.0 feet	4.0 feet
		Flow in cubic feet per second per foot of weir crest						
1.05	12⅝	......	4.14	3.98	3.82	3.74	3.66	3.62
1.06	12¾	......	4.21	4.04	3.88	3.80	3.71	3.67
1.07	12 13/16	......	4.27	4.11	3.94	3.85	3.77	3.73
1.08	12 15/16	......	4.34	4.17	4.00	3.91	3.82	3.78
1.09	13 1/16	......	4.41	4.24	4.05	3.97	3.88	3.83
1.10	13 3/16	......	4.48	4.30	4.12	4.02	3.93	3.89
1.11	13 5/16	......	4.54	4.36	4.17	4.09	3.99	3.94
1.12	13 7/16	......	4.61	4.42	4.23	4.14	4.04	3.99
1.13	13 9/16	......	4.68	4.49	4.29	4.19	4.10	4.05
1.14	13 11/16	......	4.75	4.55	4.36	4.26	4.15	4.11
1.15	13 13/16	......	4.82	4.62	4.41	4.31	4.21	4.16
1.16	13 15/16	......	4.89	4.68	4.47	4.37	4.27	4.22
1.17	14 1/16	......	4.96	4.75	4.54	4.44	4.33	4.27
1.18	14 3/16	......	5.03	4.82	4.60	4.49	4.38	4.33
1.19	14¼	......	5.10	4.88	4.67	4.55	4.44	4.39
1.20	14⅜	......	5.17	4.95	4.72	4.61	4.50	4.44
1.21	14½	......	5.25	5.02	4.79	4.67	4.56	4.50
1.22	14⅝	......	5.32	5.09	4.85	4.73	4.61	4.56
1.23	14¾	......	5.39	5.16	4.92	4.79	4.68	4.61
1.24	14⅞	......	5.47	5.22	4.98	4.88	4.73	4.67
1.25	15	......	5.54	5.29	5.05	4.92	4.79	4.73
1.26	15⅛	......	......	5.36	5.10	4.98	4.85	4.79
1.27	15¼	......	......	5.43	5.17	5.04	4.91	4.84
1.28	15⅜	......	......	5.51	5.24	5.10	4.97	4.90
1.29	15½	......	......	5.57	5.30	5.16	5.03	4.96
1.30	15⅝	......	......	5.64	5.36	5.23	5.09	5.02
1.31	15¾	......	......	5.72	5.44	5.29	5.16	5.08
1.32	15 13/16	......	......	5.79	5.50	5.36	5.22	5.14
1.33	15 15/16	......	......	5.86	5.57	5.42	5.28	5.20
1.34	16 1/16	......	......	5.93	5.63	5.48	5.33	5.26
1.35	16 3/16	......	......	6.01	5.71	5.56	5.40	5.32
1.36	16 5/16	......	......	6.08	5.77	5.62	5.46	5.38
1.37	16 7/16	......	......	6.15	5.84	5.68	5.52	5.45
1.38	16 9/16	......	......	6.22	5.90	5.75	5.58	5.51
1.39	16 11/16	......	......	6.30	5.98	5.81	5.65	5.57
1.40	16 13/16	......	......	6.38	6.04	5.87	5.71	5.62
1.41	16 15/16	......	......	6.46	6.12	5.95	5.78	5.69
1.42	17 1/16	......	......	6.52	6.18	6.01	5.84	5.75
1.43	17 3/16	......	......	6.60	6.26	6.08	5.91	5.82
1.44	17¼	......	......	6.68	6.32	6.15	5.97	5.88
1.45	17⅜	......	......	6.76	6.40	6.21	6.03	5.94
1.46	17½	......	......	6.84	6.46	6.28	6.09	6.00
1.47	17⅝	......	......	6.91	6.53	6.35	6.17	6.06
1.48	17¾	......	......	6.99	6.60	6.41	6.23	6.12
1.49	17⅞	......	......	7.07	6.68	6.49	6.29	6.20
1.50	18	......	......	7.15	6.75	6.56	6.36	6.26

RATING FLUMES

On many streams the steep slopes, gravel and debris make the use of weirs or orifices impracticable. The flow of such streams may be measured by constructing a rating flume and calibrating it by determining the relationship between the discharge and depth of water in the flume. The rating can be done by measuring the water at various gauge heights with a current meter. The services of a competent engineer should be sought to rate the flume. Once the device is calibrated the discharge can be determined by reading the gauge placed in the flume; but if deposits of silt, growth of weeds, or other obstacles change the conditions under which the flume was rated, it must be re-rated.

The flume should be so located that the water enters parallel to the axis of the flume and in such a position that the depth of water in the flume is not affected by backwater or diversions immediately above or below the structure.

The Parshall flume is an excellent permanent rating flume.

SUBMERGED ORIFICES

For sections in which the slope of the ditch or channel is so flat that it is difficult to get the required head for flow over a weir and where the waters carry considerable silt, a submerged orifice is sometimes used.

An orifice is a hole or opening cut in a bulkhead through which water flows. If the opening is below the water surface on both sides of the bulkhead, it is said to be submerged. When the water surface on the downstream side is below the opening, it is said to have a free discharge. Partial submergence occurs when the downstream water surface is between the elevations of the top and bottom of the orifice. This condition should be avoided. The submerged orifice is considered here as it is more adaptable for general use under the heads available.

Submerged orifices may be divided into two types: (1) those having orifices of fixed dimensions and (2) those built so the height of opening may be varied. A standard submerged orifice has fixed dimensions. The opening is sharp-edged and usually rectangular, with the width being from two to six times the height. The adjustable submerged orifice is one in which the height of opening and head may be varied to fit the conditions. It is usually built with suppressed side contractions. The ordinary form is the simple headgate. The standard submerged orifice is the more reliable of these two types.

Submerged Orifice With Fixed Dimensions—The Amount of water that passes through a submerged orifice of fixed dimensions is determined by the difference in elevation of water surface upstream and downstream from the bulkhead. Figure 14 shows diagrammatically the flow through a submerged orifice. As the head H increases the discharge increases.

The depth of water or head may be measured by using carpenters' rules or by specially constructed scales like those already suggested for weirs. One scale should be placed on the upstream side of the orifice and one on the downstream side with the zero end of each scale at the same level near the top of the structure. The head on the orifice is equal to the difference in the scale readings.

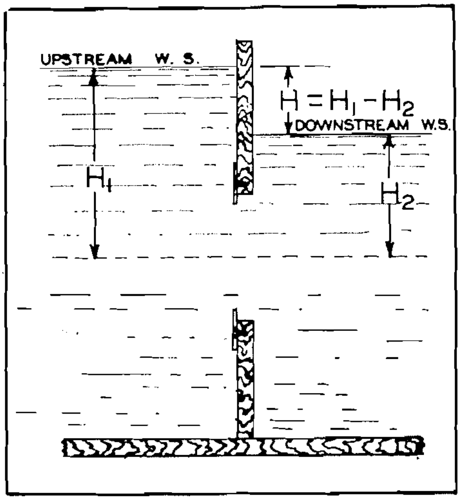

Fig. 14. Diagrammatic sketch showing flow through a submerged orifice.

For a ditch having flat grades, the allowable difference in water level upstream and downstream from the orifice is limited. Therefore, the size opening should be adapted to the head available and the size of stream.

Rules for installing submerged orifices, as set forth by the U. S. Reclamation Service,[3] are as follows:

"(a) The upstream edges of the orifice should be sharp and smooth and the distance of each from the bounding surfaces of the channel both on the upstream and on the downstream side should preferably be not less than twice the least dimension of the orifice.

"(b) The upstream face of the orifice wall should be vertical.

"(c) The top and bottom edges should be level from end to end.

"(d) The sides should be truly vertical.

"(e) The head on the orifice that should be measured is the actual difference in elevation between the water surface on the upstream side of the orifice and the water surface on the downstream side thereof.

"(f) The cross-sectional area of the water prism for 20 to 30 feet from the orifice, on the upstream and on the downstream side thereof, should be at least six times the cross-sectional area of the orifice.

"(g) Correction should be made for velocity of approach where appreciable errors are caused by neglecting the head due to it."

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[3]"Manual for Measurement of Irrigation Water." U. S. Department of Interior, Bureau of Reclamation. April, 1947.

The main advantage of the submerged orifice is that it can be used on relatively level canals where it is not possible to obtain sufficient fall for weir measurements. The submerged orifice is subject to the same disadvantages as the weir—collecting floating debris, sand, and sediment. If the pond in front of the orifice is allowed to silt up, the accuracy of the device is destroyed. Figure 15 shows a perspective of a wooden submerged orifice as seen from upstream.

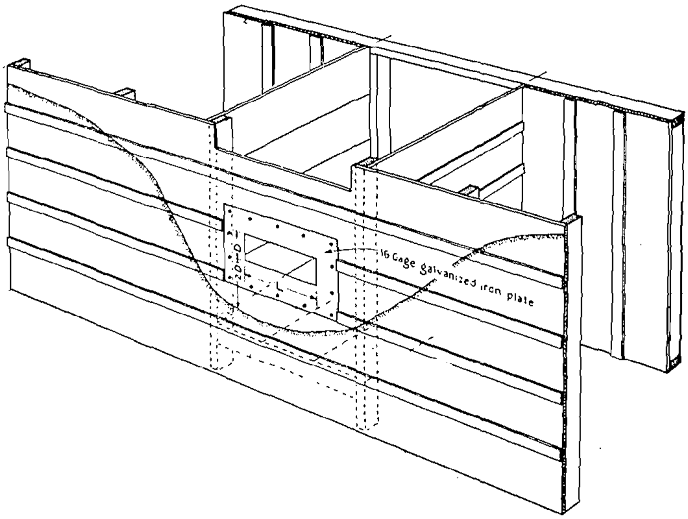


Fig. 15. Perspective of wooden submerged orifice structure.

Determination of Discharge—Discharges for submerged orifices of fixed dimensions are given by the curves in Figure 16. These curves can be used directly only in connection with an orifice having one of the eight cross-sectional areas given—0.25, 0.5, 0.75 of a square foot, and so on up to 2 square feet. For convenience in making measurements, an orifice should be so designed that its cross-sectional area is equal to one of those given in Figure 16. Discharges through orifices having cross-sectional areas other than those given by the curve may be computed by proportion. For the example indicated on the figure the discharge equals 3.78 c.f.s. for an orifice area of 1.0 sq. ft. and a head of 0.6 ft. If the orifice area were 0.6 of a square foot, the discharge would be 0.6 x 3.78 = 2.27 c.f.s. under the same head.

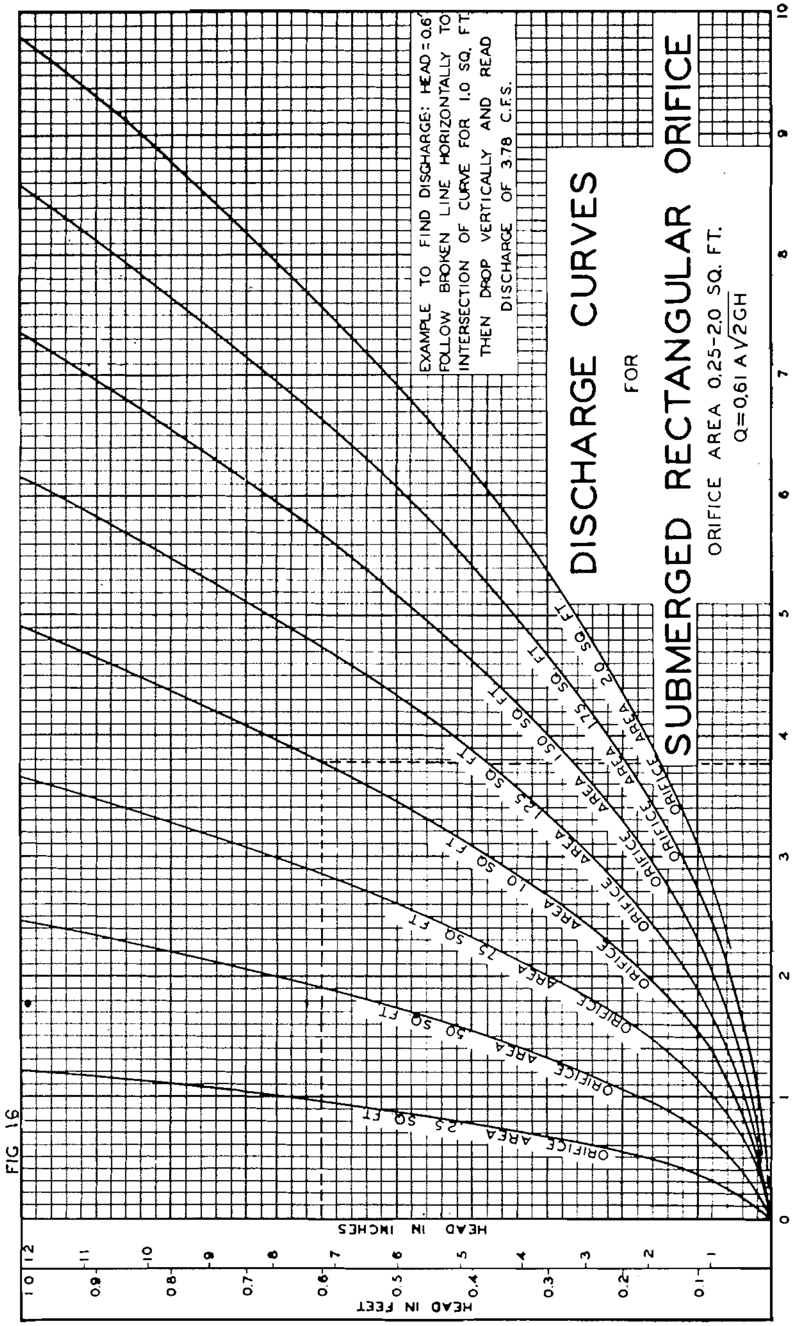


Fig. 16. Discharge curves for submerged orifices with fixed dimensions.

TABLE 8

Flow Through Rectangular Submerged Orifices in Cubic Feet Per Second*

Head, H, in feet	Head, in inches (approx.)	Cross-sectional area of orifice, A						
		0.25 sq. ft.	0.333 sq. ft.	0.50 sq. ft.	0.75 sq. ft.	1.00 sq. ft.	1.50 sq. ft.	2.00 sq. ft.
		Flow in cubic feet per second						
0.01	⅛	0.122	0.163	0.245	0.367	0.489	0.73	0.98
0.02	¼	0.173	0.230	0.346	0.518	0.691	1.04	1.38
0.03	⅜	0.212	0.282	0.424	0.635	0.847	1.27	1.69
0.04	½	0.245	0.326	0.489	0.734	0.978	1.47	1.96
0.05	⅝	0.273	0.364	0.547	0.820	1.09	1.64	2.19
0.06	¾	0.300	0.399	0.599	0.899	1.20	1.80	2.40
0.07	13/16	0.324	0.431	0.647	0.971	1.29	1.94	2.59
0.08	15/16	0.346	0.461	0.691	1.04	1.38	2.07	2.77
0.09	1 1/16	0.367	0.489	0.734	1.10	1.47	2.20	2.94
0.10	1 3/16	0.387	0.518	0.773	1.16	1.56	2.32	3.09
0.11	1 5/16	0.406	0.540	0.811	1.22	1.62	2.43	3.24
0.12	1 7/16	0.424	0.564	0.847	1.27	1.69	2.54	3.39
0.13	1 9/16	0.441	0.587	0.882	1.32	1.76	2.65	3.53
0.14	1 11/16	0.458	0.609	0.915	1.37	1.83	2.75	3.66
0.15	1 13/16	0.474	0.631	0.947	1.42	1.90	2.84	3.79
0.16	1 15/16	0.489	0.651	0.978	1.47	1.96	2.93	3.91
0.17	2 1/16	0.504	0.671	1.01	1.51	2.02	3.02	4.03
0.18	2 3/16	0.519	0.691	1.04	1.56	2.08	3.11	4.15
0.19	2¼	0.533	0.710	1.07	1.60	2.13	3.20	4.26
0.20	2⅜	0.547	0.729	1.09	1.64	2.19	3.28	4.38
0.21	2½	0.561	0.746	1.12	1.68	2.24	3.36	4.48
0.22	2⅝	0.574	0.765	1.15	1.72	2.30	3.46	4.59
0.23	2¾	0.587	0.781	1.17	1.76	2.35	3.52	4.69
0.24	2⅞	0.600	0.798	1.20	1.80	2.40	3.60	4.79
0.25	3	0.612	0.815	1.22	1.83	2.45	3.67	4.89
0.26	3⅛	0.624	0.831	1.25	1.87	2.49	3.74	4.99
0.27	3¼	0.636	0.846	1.27	1.91	2.54	3.81	5.08
0.28	3⅜	0.646	0.862	1.29	1.94	2.59	3.88	5.18
0.29	3½	0.659	0.878	1.32	1.98	2.64	3.96	5.28
0.30	3⅝	0.670	0.892	1.34	2.01	2.68	4.02	5.36
0.31	3¾	0.681	0.908	1.36	2.05	2.73	4.09	5.45
0.32	3 13/16	0.692	0.920	1.38	2.07	2.76	4.15	5.53
0.33	3 15/16	0.703	0.936	1.41	2.11	2.81	4.22	5.62
0.34	4 1/16	0.713	0.950	1.43	2.14	2.85	4.28	5.70
0.35	4 3/16	0.724	0.963	1.45	2.17	2.89	4.34	5.78
0.36	4 5/16	0.734	0.976	1.47	2.20	2.93	4.40	5.87
0.37	4 7/16	0.745	0.991	1.49	2.23	2.98	4.46	5.95
0.38	4 9/16	0.754	1.00	1.51	2.26	3.02	4.52	6.03
0.39	4 11/16	0.764	1.02	1.53	2.29	3.05	4.58	6.11
0.40	4 13/16	0.774	1.03	1.55	2.32	3.09	4.64	6.19

*Computed from the formula $Q = 0.61\ A\ \sqrt{2gH}$.

TABLE 8—(Continued)

Head, H, in feet	Head, in inches (approx.)	Cross-sectional area of orifice, A						
		0.25 sq. ft.	0.333 sq. ft.	0.50 sq. ft.	0.75 sq. ft.	1.00 sq. ft.	1.50 sq. ft.	2.00 sq. ft.
		Flow in cubic feet per second						
0.41	4 15/16	0.783	1.04	1.57	2.35	3.13	4.70	6.27
0.42	5 1/16	0.792	1.06	1.59	2.38	3.17	4.75	6.34
0.43	5 3/16	0.802	1.07	1.60	2.41	3.21	4.81	6.42
0.44	5¼	0.811	1.08	1.62	2.43	3.24	4.87	6.49
0.45	5⅜	0.820	1.09	1.64	2.46	3.28	4.92	6.56
0.46	5½	0.829	1.10	1.66	2.49	3.32	4.98	6.64
0.47	5⅝	0.839	1.12	1.68	2.52	3.36	5.04	6.71
0.48	5¾	0.847	1.13	1.70	2.54	3.39	5.08	6.78
0.49	5⅞	0.856	1.14	1.71	2.57	3.42	5.14	6.85
0.50	6	0.865	1.15	1.73	2.59	3.46	5.19	6.92
0.51	6⅛	0.873	1.16	1.75	2.62	3.49	5.24	6.99
0.52	6¼	0.882	1.17	1.76	2.65	3.53	5.29	7.05
0.53	6⅜	0.890	1.19	1.78	2.67	3.56	5.34	7.12
0.54	6½	0.898	1.20	1.80	2.70	3.59	5.39	7.19
0.55	6⅝	0.907	1.21	1.81	2.72	3.63	5.44	7.25
0.56	6¾	0.915	1.22	1.83	2.75	3.66	5.49	7.32
0.57	6 13/16	0.923	1.23	1.85	2.77	3.69	5.54	7.38
0.58	6 15/16	0.931	1.24	1.86	2.79	3.73	5.59	7.45
0.59	7 1/16	0.939	1.25	1.88	2.82	3.76	5.64	7.51
0.60	7 3/16	0.947	1.26	1.90	2.84	3.79	5.68	7.58
0.61	7 5/16	0.955	1.27	1.91	2.87	3.82	5.73	7.64
0.62	7 7/16	0.963	1.28	1.93	2.89	3.85	5.78	7.70
0.63	7 9/16	0.971	1.29	1.94	2.91	3.88	5.82	7.76
0.64	7 11/16	0.978	1.30	1.96	2.93	3.91	5.87	7.82
0.65	7 13/16	0.986	1.31	1.97	2.96	3.94	5.92	7.89
0.66	7 15/16	0.993	1.32	1.99	2.98	3.97	5.96	7.95
0.67	8 1/16	1.00	1.33	2.00	3.00	4.00	6.01	8.01
0.68	8 3/16	1.01	1.34	2.02	3.02	4.03	6.05	8.06
0.69	8¼	1.02	1.35	2.03	3.05	4.06	6.10	8.13
0.70	8⅜	1.02	1.36	2.05	3.07	4.09	6.14	8.18
0.71	8½	1.03	1.37	2.06	3.09	4.12	6.19	8.25
0.72	8⅝	1.04	1.38	2.08	3.11	4.15	6.23	8.30
0.73	8¾	1.05	1.39	2.09	3.14	4.18	6.27	8.36
0.74	8⅞	1.05	1.40	2.10	3.16	4.21	6.31	8.42
0.75	9	1.06	1.41	2.12	3.18	4.24	6.36	8.48
0.76	9⅛	1.07	1.42	2.13	3.20	4.26	6.40	8.53
0.77	9¼	1.07	1.43	2.15	3.22	4.29	6.43	8.58
0.78	9⅜	1.08	1.44	2.16	3.24	4.32	6.48	8.64
0.79	9½	1.09	1.45	2.17	3.26	4.35	6.52	8.70
0.80	9⅝	1.09	1.46	2.19	3.28	4.38	6.56	8.75

If no curves or tables of discharge are available, this orifice can still be used as the discharge can be determined by use of the formula:

$$Q = 4.89\, A\sqrt{H}$$

Where Q = discharge in cubic feet per second (c.f.s)
A = area of opening in square feet
H = difference in head in feet.

Example: Area of opening = 2 square feet
Measured difference in head = 0.5 foot.
Discharge $Q = 4.89 \times 2 \times \sqrt{0.5} = 6.92$ c.f.s.

COMBINATION HEADGATE AND MEASURING DEVICES[4]

The Bureau of Reclamation has developed what is known as a constant-head, adjustable orifice turnout; it replaces the common turnout-gate-weir combination. This device was designed to control and accurately measure irrigation water without the excessive amount of adjustment and walking usually required for the gate weir combination.

TABLE 9—Discharge tables for the constant-head orifice turnout. Capacity 20 second-feet. Gate size 24 inches by 30 inches. Constant-head = 0.2 foot.

Discharge (second-feet)	Gate opening in feet		Discharge (second-feet)	Gate opening in feet	
	2 gates	1 gate		2 gates	1 gate
0.5	0.04	0.08	10.5	0.83	
1.0	.08	.16	11.0	.87	
1.5	.12	.24	11.5	.91	
2.0	.16	.32	12.0	.95	
2.5	.20	.40	12.5	.99	
3.0	.24	.48	13.0	1.03	
3.5	.28	.56	13.5	1.07	
4.0	.32	.64	14.0	1.10	
4.5	.36	.72	14.5	1.14	
5.0	.40	.79	15.0	1.18	
5.5	.44	.87	15.5	1.22	
6.0	.48	.95	16.0	1.26	
6.5	.52	1.03	16.5	1.30	
7.0	.56	1.10	17.0	1.34	
7.5	.60	1.18	17.5	1.37	
8.0	.64	1.26	18.0	1.41	
8.5	.68	1.34	18.5	1.45	
9.0	.72	1.41	19.0	1.49	
9.5	.76	1.49	19.5	1.53	
10.0	.79	1.56	20.0	1.56	

[4]"Manual for Measurement of Irrigation Water." U. S. Department of Interior, Bureau of Reclamation. 1946.

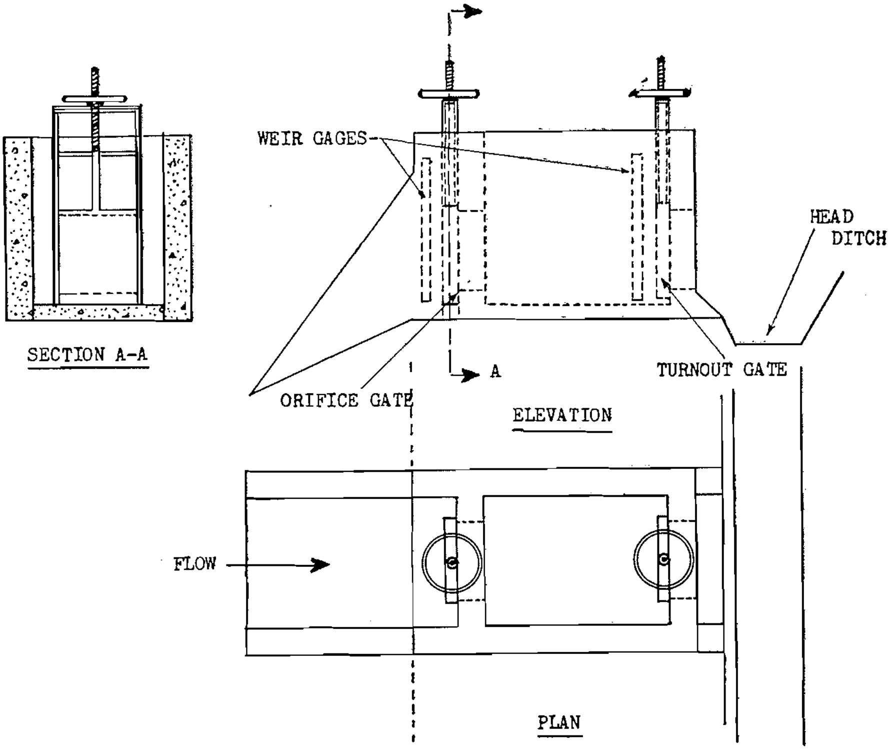


Fig. 17. Constant-Head Orifice.

TABLE 10—Discharge tables for the constant-head orifice turnout. Capacity 10 second feet. Gate size 18 inches by 24 inches. Constant-head = 0.2 foot.

Discharge (second-feet)	Gate opening in feet		Discharge (second-feet)	Gate opening in feet	
	2 gates	1 gate		2 gates	1 gate
0.5	0.05	0.10	5.5	0.55	
1.0	.10	.20	6.0	.60	
1.5	.15	.30	6.5	.65	
2.0	.20	.40	7.0	.70	
2.5	.25	.50	7.5	.74	
3.0	.30	.60	8.0	.79	
3.5	.35	.70	8.5	.84	
4.0	.40	.79	9.0	.89	
4.5	.45	.89	9.5	.94	
5.0	.50	.99	10.0	.99	

The structure consists essentially of two gates, the adjustable orifice gate and the turnout gate. These are placed on the upstream and downstream sides, respectively, of a stilling pool which is part of the turnout.

The 18 x 24-inch and 24 x 30-inch gates are used as orifices. These gates are used in single-barrel and double-barrel turnouts. Figure 17 illustrates a single-barrel turnout.

The orifice is designed to operate at 0.2 foot effective head, which is adjusted by the turnout (downstream) gate after the orifice gate is opened to a height determined from tables compiled for various discharges and gate openings. Details of this device are shown on Bureau drawings 40-D-3672 and 40-D-3673k which may be obtained from the Bureau of Reclamation, Denver, Colorado.

The computed discharge tables included on the drawings are based on an assumed coefficient of approximately 0.66 in the following equation:

$$Q = C\,A\sqrt{2gH}$$

where

Q = discharge in cubic feet per second

H = differential head on orifice gate = 0.2 foot

A = area of the orifice gate opening in square feet

C = the coefficient of discharge (approximately 0.66).

G = acceleration of gravity = 32.2 feet per second per second

Calibration tests on a model of the constant head orifice turnout with a scale ratio of 1 in the model to 2 in the prototype, were conducted in the Bureau's hydraulic laboratory in the customhouse at Denver, Colorado. Tests were made using the following conditions:

1. Two different gate sizes corresponding to 18 x 24 inches and 24 x 30 inches in the prototype.
2. Four different approach floors corresponding to those shown on the plain drawings.
3. Single-barrel type.
4. Double-barrel type with both gates open equal amounts, and double-barrel type with one gate open and one gate closed.

Tests[5] on plan 1 (See Bureau drawing 40-D-3672, double-barrel design with uniform gate openings) showed that the discharge coefficient was essentially constant for a given gate opening for various canal water surface elevations, but increased slightly with increased gate openings up to a prototype gate opening of 1.5 feet. For larger gate openings, the coefficient increased appreciably with an increase in the gate opening; also, the coefficient varied inconsistently with a variation of canal water surface elevations. The same results were obtained in plans 2, 3, and 4.

[5]Tests by U.S.B.R.

Operation with only one of the two gates open gave satisfactory coefficients for small gate openings, but for larger gate openings it was difficult to obtain correct differential head because of rough and tilted water surface between the orifice gate and the turnout gate.

The single-barrel type gave similar operation to that of the double-barrel type with both gates opened equal amounts, and the same discharge coefficients were obtained.

Table 30 and 31 give discharge with increases of 0.5 second foot for various gate openings of both of the double-barrel and single-barrel types of constant-head orifice-turnout structures. The constant-head differential is 0.2 foot.

The tests showed that the coefficient of discharge C in the formula $Q = C\sqrt{A\ 2gH}$ varied from 0.685 to 0.713.

COMMERCIAL GATES

Another combination headgate and measuring device that has proved successful is a commercial gate sold under the name of Calco Metergate.[6] This gate is available in sizes from 8 inches to 48 inches in diameter.

The principle of operation of these gates is similar to that of the submerged orifice or to the double orifice gate just described. They are especially adapted for use at lateral outlets for they serve as headgates and also as water measuring devices. Figure 18 illustrates the installation of the gate for a lateral outlet through a canal bank. In installing, care must be taken to see

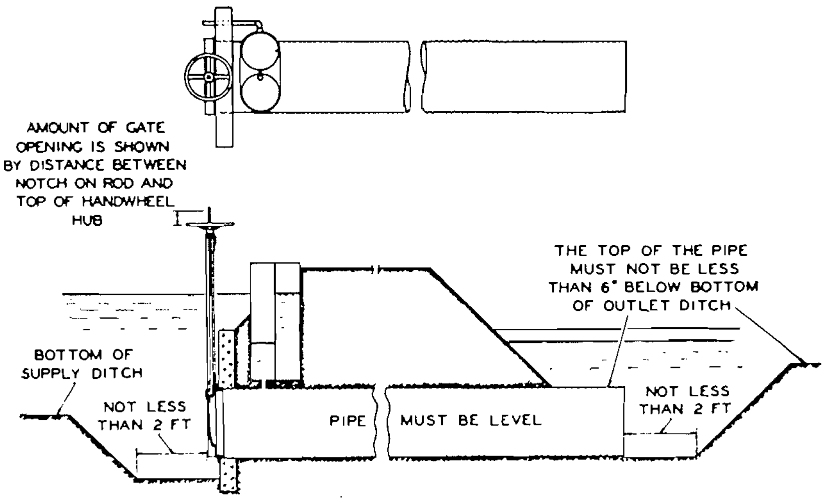


Fig. 18. Calibrated commercial gate installed in canal bank.

[6]Handbook of Water Control, by the Hardesty Division, Armco Drainage & Metal Products Company. 1943.

that the outlet pipe is low enough to insure the proper submergence of the outlet, which should not be less than 6 inches under lowest conditions.

Two measurements are necessary for finding the discharge: the amount of gate opening as found by measuring the length of rod coming through the handwheel and the difference in the elevations of the upstream and downstream water surfaces. Knowing these two measurements, one may enter tables or curves supplied by the manufacturer of the gate and find the discharge.

For a loss of head ranging from 1 inch to 18 inches, discharges from approximately one quarter second foot to 78 second feet may be measured through Standard Calco Metergates.

PARSHALL MEASURING FLUME

The Parshall Measuring Flume[7] is a device having a converging inlet section, a throat section with straight parallel sides, and an outlet section which diverges (See Figure 19). The Parshall Measuring Flume is a water measuring device by which the water flowing in an open channel can be measured satisfactorily with a minimum loss of head. The loss of head for

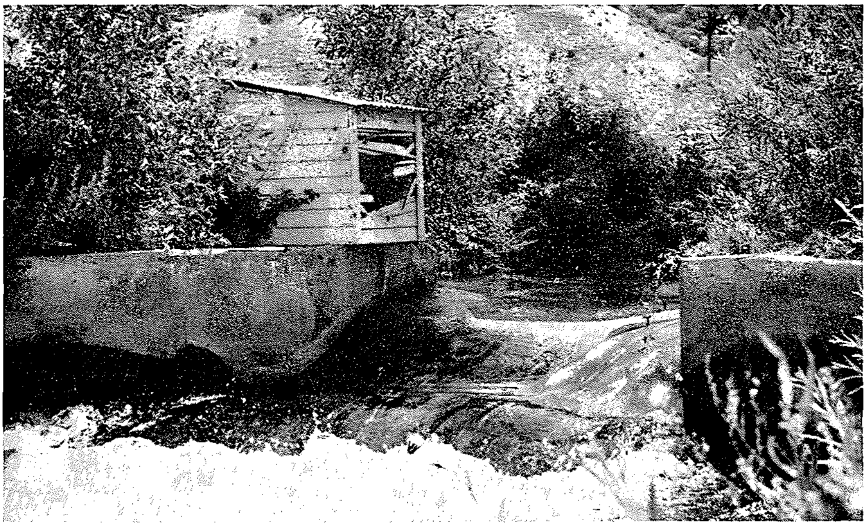


Fig. 19. Eight-foot Parshall Measuring Flume located in the Logan Northern Canal near Logan, Utah.

[7]Colorado Experiment Station Bulletin 423, "The Parshall Measuring Flume." 1936

the free flow limit is only about 25 per cent of that for the overpour weir. The accuracy of discharge measurements with this flume, under normal operating conditions, is probably within 2 to 5 per cent.

The Parshall flume may be operated as a free flow single head device or under submerged flow conditions where two heads are involved. In this bulletin, only the free flow single head device will be considered. Figure 20 shows a plan and longitudinal section of the Parshall flume together with a letter on each dimension line. Table 11 gives the value of the dimensions for various size flumes having a capacity varying from 0.35 c.f.s. to 176 c.f.s. Flumes of 50-foot throat width with a capacity of 3000 second feet are possible.[8] The Parshall flume consists of a box of wood, concrete, or metal with a level floor, a coverging section and vertical side walls. At the end of the converging section the floor slopes downward 9 inches to 2 feet. The outlet section is 3 feet long and diverges. The floor of the outlet section rises 6 inches in 3 feet. The lower end of the outlet is 3 inches lower than the crest. These dimensions are for flumes having a throat width of 1 foot or more.

. For free flow conditions, the submergence must not exceed 70 per cent for Parshall flumes having a throat width of 1 foot or more; for smaller flumes, such as a 3-inch flume, the submergence should not exceed 50 per cent.

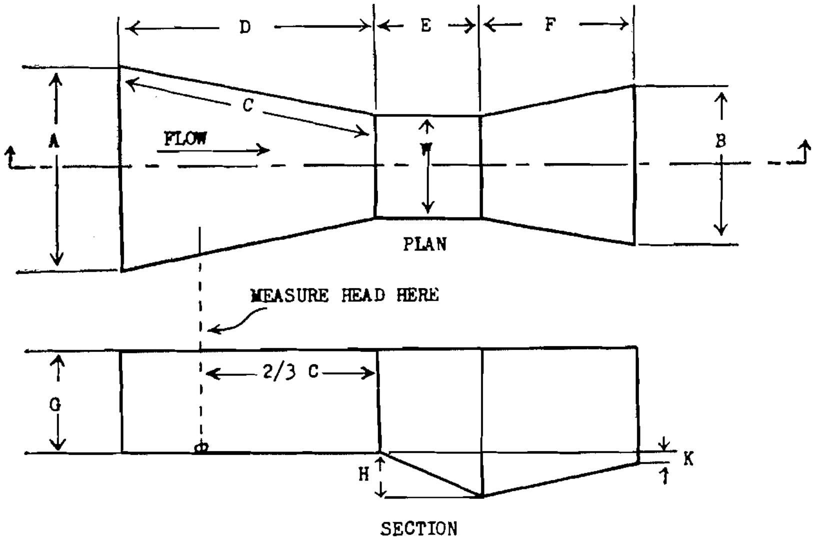


Fig. 20. Plan and longitudinal section of Parshall measuring flume.

[8]Colorado Experiment Station Bulletin 386, "Parshall Flumes of Large Size." 1932

TABLE 11—A Table of Dimensions and Capacities for Parshall Flumes

Throat Width A	Dimensions in Feet and Inches									Free Flow Capacities	
ft. in.	A	B	C	⅔ C	D	E	F	G	H	K	Minimum c.f.s.	Maximum c.f.s.
0′ 3″	0′10 3/16″	0′ 7″	1′ 6⅜″	1′ 0¼″	1′ 6″	0′ 6″	1′ 0″	1′ 3″	0′ 2¼″	0′ 1″	.03	.6
0′ 6″	1′ 3½″	1′ 3½″	2′ 0 7/16″	1′ 4 5/16″	2′ 0″	1′ 0″	2′ 0″	1′ 6″	0′ 4½″	0′ 3″	.05	2.9
0′ 9″	1′10⅝″	1′ 3″	2′10⅝″	1′11⅛″	2′ 10″	1′ 0″	1′ 6″	2′ 0″	0′ 4½″	0′ 3″	.1	5.1
1′ 0″	2′ 9¼″	2′ 0″	4′ 6″	3′ 0″	4′ 4⅞″	2′ 0″	3′ 0″	3′ 0″	0′ 9″	0′ 3″	.4	16.0
2′ 0″	3′11½″	3′ 0″	5′ 0″	3′ 4″	4′10⅞″	2′ 0″	3′ 0″	3′ 0″	0′ 9″	0′ 3″	.7	33.0
3′ 0″	5′ 1⅞″	4′ 0″	5′ 6″	3′ 8″	5′ 4¾″	2′ 0″	3′ 0″	3′ 0″	0′ 9″	0′ 3″	1.0	50.0
4′ 0″	6′ 4¼″	5′ 0″	6′ 0″	4′ 0″	5′10⅝″	2′ 0″	3′ 0″	3′ 0″	0′ 9″	0′ 3″	1.3	68.0
5′ 0″	7′ 6⅝″	6′ 0″	6′ 6″	4′ 4″	6′ 4½″	2′ 0″	3′ 0″	3′ 0″	0′ 9″	0′ 3″	2.2	86.0
6′ 0″	8′ 9″	7′ 0″	7′ 0″	4′ 8″	6′10⅜″	2′ 0″	3′ 0″	3′ 0″	0′ 9″	0′ 3″	2.6	104.0
7′ 0″	9′11⅜″	8′ 0″	7′ 6″	5′ 0″	7′ 4¼″	2′ 0″	3′ 0″	3′ 0″	0′ 9″	0′ 3″	4.1	121.0
8′ 0″	11′ 1¾″	9′ 0″	8′ 0″	5′ 4″	7′10⅛″	2′ 0″	3′ 0″	3′ 0″	0′ 9″	0′ 3″	4.6	140.0
10′ 0″*	15′ 7¼″	12′ 0″	9′ 0″	6′ 0″	14′ 0″	3′ 0″	6′ 0″	3′ 0″	1′ 1.5″	0′ 6″	6.0	200.0

*For Flumes of 10′-00″ and larger dimensions see "Parshall Flumes of Larger Sizes," Bulletin 426-A, Colorado A. & M. Experiment Station.

Fig. 21. One-foot Parshall measuring flume installed near Smithfield, Utah.

Per cent submergence means the percentage that the downstream head is of the upstream head. Figure 21 shows one of a large number of small flumes installed in Cache County, Utah.

The Parshall flume, like any other water-measuring structure, must be properly installed and maintained to give best results. This requires that the proper size flume for the conditions present be chosen. The maximum quantity of water to be measured must first be determined, then the amount of head available for use through the flume. To assist in the selection of the proper size of flume for certain requirements, the diagram shown in Figure 22 has been prepared. Use of this diagram may best be illustrated by an example: Let it be required to find the smallest size flume necessary to measure a discharge of 5 second-feet with 62 per cent submergence and with a loss of head not exceeding one-half foot. Enter the diagram at the lower left and follow vertically on the line 62 until the curved discharge line 5 is reached. At this point move horizontally to the right until the vertical line 0.50 is intersected. Note that this point is just a little to the right of the diagonal line marked 1 foot throat width. This indicates that a flume width of just a little less than 1 foot would be necessary but a 1 foot width would be used. Discharge curves for Parshall flumes having throat widths from 6 inches to 10 feet are given in Figures 23 and 24.

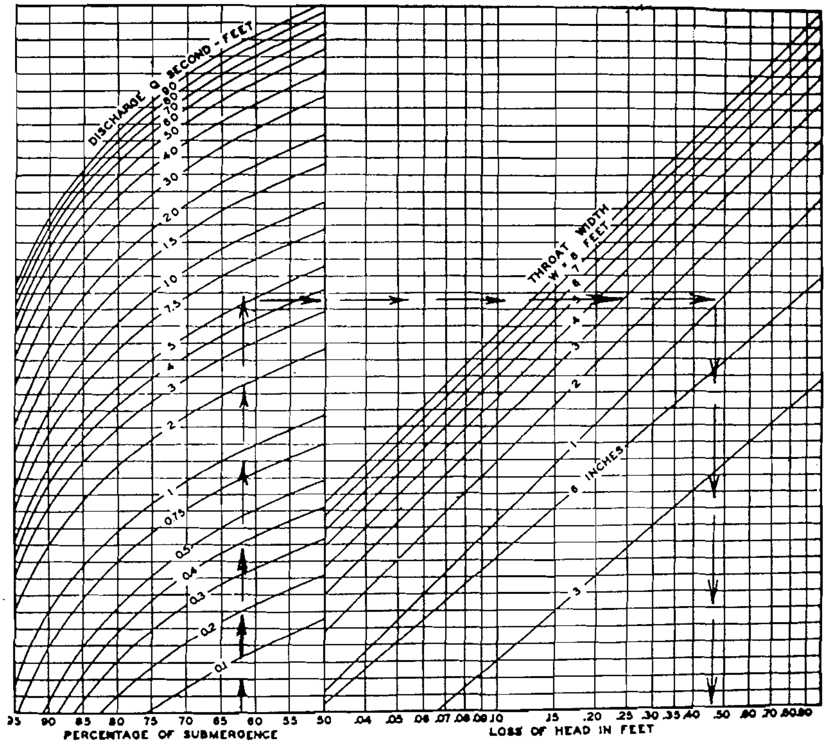


Fig. 22. **Diagram for determining the loss of head through the Parshall measuring flume.**

Directions for Placing Flumes, and Example to Determine Correct Setting of Crest Elevation:

(1) Locate the high water line on ditch bank where the flume is to be installed.

(2) Select from capacity or discharge curves, Figure 23, the proper depth of water or head H_A that corresponds with the maximum capacity of ditch. (Assume that a 1-foot flume is to be used and that the maximum discharge is 4.0 second-feet; therefore, the depth of water on the crest H_A is 1.0 feet.)

(3) Place the floor of the flume at a depth not more than 70 per cent of H_A below the high water line. In general the floor of the flume should be placed as high in the ditch as the grade and other conditions permit. For example, allow 70 per cent submergence, then $0.7 \times 1.0 = 0.7$ feet. Therefore, set flume crest no more than 0.7 feet below high water mark. The loss of head will be 1.0 feet – 0.7 feet = 0.3 feet.)

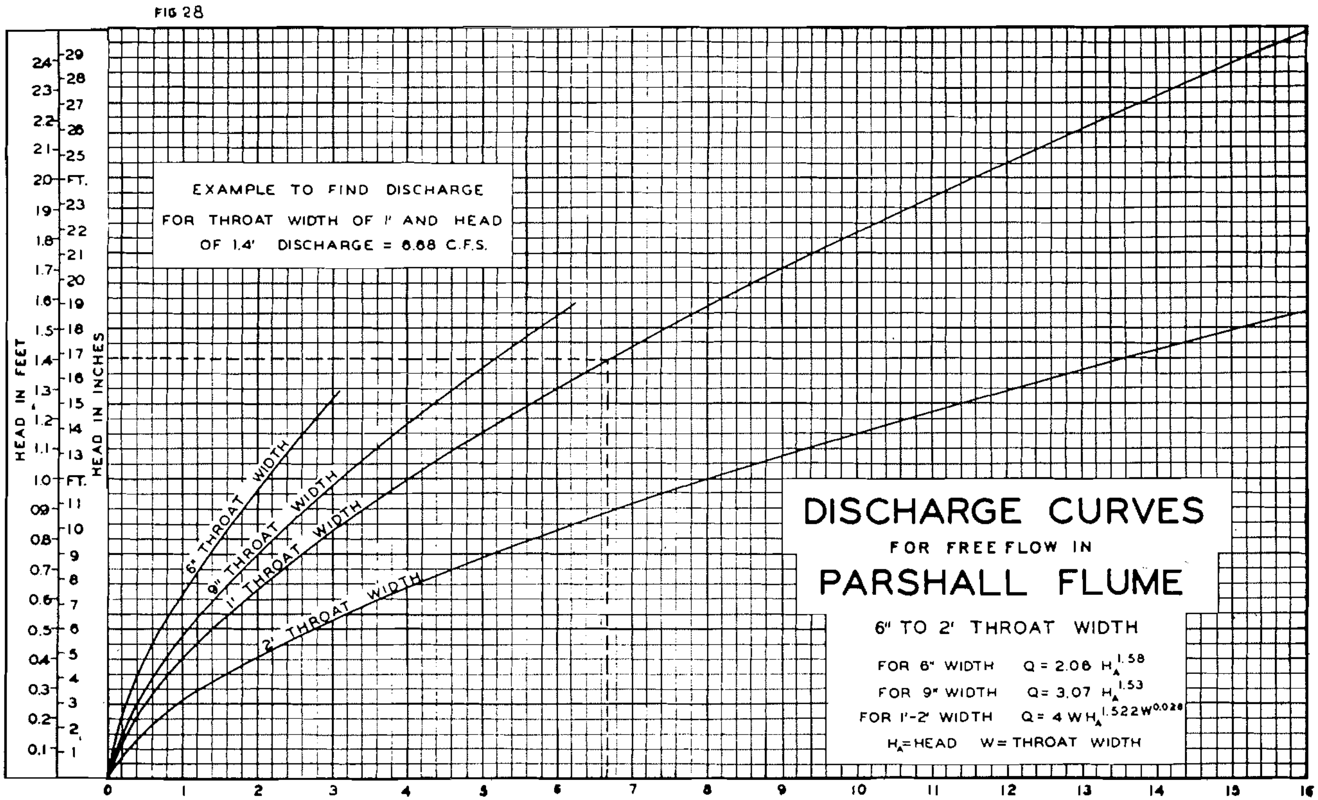


Fig. 23. Discharge curves for free flow in Parshall flume. Throat width 6"-2'.

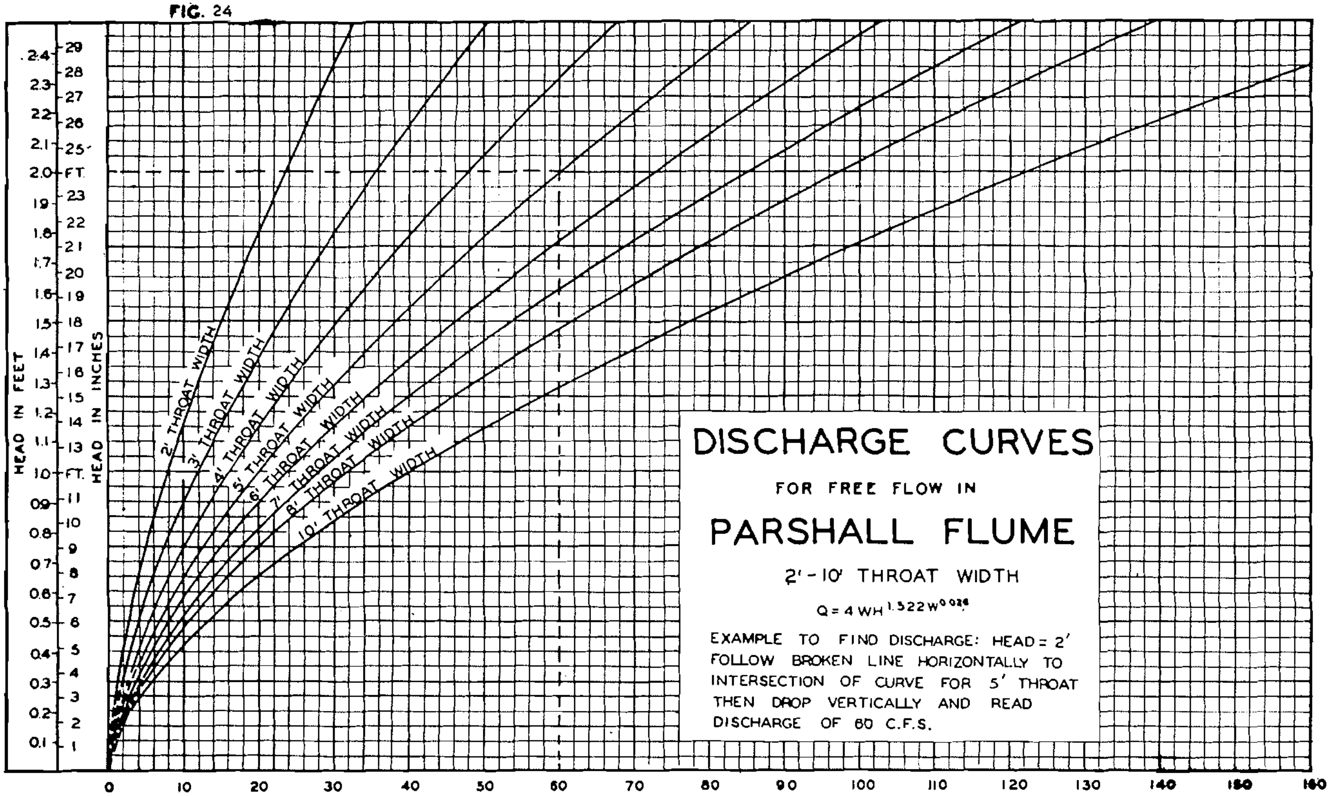


Fig. 24. Discharge curves for free flow in Parshall flume. Throat width 2'-10'.

TABLE 12

Free Flow Through Parshall Measuring Flumes*†

Upper head, *Ha*		Throat width											
Feet	Inches (approx.)	3 inches	6 inches	9 inches	1 foot	2 feet	3 feet	4 feet	5 feet	6 feet	7 feet	8 feet	10 feet
		Flow in cubic feet per second											
0.10	1 3/16	0.028	0.05	0.09	......	......	......	......	......	......	......	......	......
0.11	1 5/16	0.033	0.06	0.10	......	......	......	......	......	......	......	......	......
0.12	1 7/16	0.037	0.07	0.12	......	......	......	......	......	......	......	......	......
0.13	1 9/16	0.042	0.08	0.14	......	......	......	......	......	......	......	......	......
0.14	1 11/16	0.047	0.09	0.15	......	......	......	......	......	......	......	......	......
0.15	1 13/16	0.053	0.10	0.17	......	......	......	......	......	......	......	......	......
0.16	1 15/16	0.058	0.11	0.19	......	......	......	......	......	......	......	......	......
0.17	2 1/16	0.064	0.12	0.20	......	......	......	......	......	......	......	......	......
0.18	2 3/16	0.070	0.14	0.22	......	......	......	......	......	......	......	......	......
0.19	2¼	0.076	0.15	0.24	......	......	......	......	......	......	......	......	......
0.20	2⅜	0.082	0.16	0.26	0.35	0.66	0.97	1.26	......	......	......	......	......
0.21	2½	0.089	0.18	0.28	0.37	0.71	1.04	1.36	......	......	......	......	......
0.22	2⅝	0.095	0.19	0.30	0.40	0.77	1.12	1.47	......	......	......	......	......
0.23	2¾	0.102	0.20	0.32	0.43	0.82	1.20	1.58	......	......	......	......	......
0.24	2⅞	0.109	0.22	0.35	0.46	0.88	1.28	1.69	......	......	......	......	......
0.25	3	0.117	0.23	0.37	0.49	0.93	1.37	1.80	2.22	2.63	......	......	......
0.26	3⅛	0.124	0.25	0.39	0.51	0.99	1.46	1.91	2.36	2.80	......	......	......
0.27	3¼	0.131	0.26	0.41	0.54	1.05	1.55	2.03	2.50	2.97	......	......	......
0.28	3⅜	0.138	0.28	0.44	0.58	1.11	1.64	2.15	2.65	3.15	......	......	......
0.29	3½	0.146	0.29	0.46	0.61	1.18	1.73	2.27	2.80	3.33	......	......	......
0.30	3⅝	0.154	0.31	0.49	0.64	1.24	1.82	2.39	2.96	3.52	4.08	4.62	......
0.31	3¾	0.162	0.32	0.51	0.68	1.30	1.92	2.52	3.12	3.71	4.30	4.88	......
0.32	3 13/16	0.170	0.34	0.54	0.71	1.37	2.02	2.65	3.28	3.90	4.52	5.13	......
0.33	3 15/16	0.179	0.36	0.56	0.74	1.44	2.12	2.78	3.44	4.10	4.75	5.39	......
0.34	4 1/16	0.187	0.38	0.59	0.77	1.50	2.22	2.92	3.61	4.30	4.98	5.66	......
0.35	4 3/16	0.196	0.39	0.62	0.80	1.57	2.32	3.06	3.78	4.50	5.22	5.93	......
0.36	4 5/16	0.205	0.41	0.64	0.84	1.64	2.42	3.19	3.95	4.71	5.46	6.20	......
0.37	4 7/16	0.213	0.43	0.67	0.88	1.72	2.53	3.34	4.13	4.92	5.70	6.48	......
0.38	4 9/16	0.222	0.45	0.70	0.92	1.79	2.64	3.48	4.31	5.13	5.95	6.76	......
0.39	4 11/16	0.231	0.47	0.73	0.95	1.86	2.75	3.62	4.49	5.35	6.20	7.05	......
0.40	4 13/16	0.241	0.48	0.76	0.99	1.93	2.86	3.77	4.68	5.57	6.46	7.34	9.1
0.41	4 15/16	0.250	0.50	0.78	1.03	2.01	2.97	3.92	4.86	5.80	6.72	7.64	9.5
0.42	5 1/16	0.260	0.52	0.81	1.07	2.09	3.08	4.07	5.05	6.02	6.98	7.94	9.8
0.43	5 3/16	0.269	0.54	0.84	1.11	2.16	3.20	4.22	5.24	6.25	7.25	8.24	10.2
0.44	5¼	0.279	0.56	0.87	1.15	2.24	3.32	4.38	5.43	6.48	7.52	8.55	10.6
0.45	5⅜	0.289	0.58	0.90	1.19	2.32	3.44	4.54	5.63	6.72	7.80	8.87	11.0
0.46	5½	0.299	0.61	0.94	1.23	2.40	3.56	4.70	5.83	6.96	8.08	9.19	11.4
0.47	5⅝	0.309	6.63	0.97	1.27	2.48	3.68	4.86	6.03	7.20	8.36	9.51	11.8
0.48	5¾	0.319	0.65	1.00	1.31	2.57	3.80	5.03	6.24	7.44	8.65	9.8	12.2
0.49	5⅞	0.329	0.67	1.03	1.35	2.65	3.92	5.20	6.45	7.69	8.94	10.2	12.6

*Parshall, R. L. The improved Venturi flume. Colorado Agr. Exp. Sta. Bul. **336**:19-23. 1928.

†Parshall, R. L. Measuring water in irrigation channels. U. S. Dept. of Agr. Farmer's Bul. **1683**:10-11.1932.

TABLE 12—(Continued)

Upper head, *Ha* — Feet	Inches (approx.)	Throat width: 3 inches	6 inches	9 inches	1 foot	2 feet	3 feet	4 feet	5 feet	6 feet	7 feet	8 feet	10 feet
		Flow in cubic feet per second											
0.50	6	0.339	0.69	1.06	1.39	2.73	4.05	5.36	6.66	7.94	9.23	10.5	13.1
0.51	6⅛	0.350	1.71	1.10	1.44	2.82	4.18	5.53	6.87	8.20	9.53	10.9	13.5
0.52	6¼	0.361	0.73	1.13	1.48	2.90	4.31	5.70	7.09	8.46	9.83	11.2	13.9
0.53	6⅜	0.371	0.76	1.16	1.52	2.99	4.44	5.88	7.30	8.72	10.1	11.5	14.3
0.54	6½	0.382	0.78	1.20	1.57	3.08	4.57	6.05	7.52	8.98	10.5	11.9	14.8
0.55	6⅝	0.393	0.80	1.23	1.62	3.17	4.70	6.23	7.74	9.25	10.8	12.2	15.2
0.56	6¾	0.404	0.82	1.26	1.66	3.26	4.84	6.41	7.97	9.52	11.1	12.6	15.7
0.57	6 13/16	0.415	0.85	1.30	1.70	3.35	4.98	6.59	8.20	9.79	11.4	13.0	16.1
0.58	6 15/16	0.427	0.87	1.33	1.75	3.44	5.11	6.77	8.43	10.1	11.7	13.3	16.6
0.59	7 1/16	0.438	0.89	1.37	1.80	3.53	5.25	6.96	8.66	10.4	12.0	13.7	17.1
0.60	7 3/16	0.450	0.92	1.40	1.84	3.62	5.39	7.15	8.89	10.6	12.4	14.1	17.5
0.61	7 5/16	0.462	0.94	1.44	1.88	3.72	5.53	7.34	9.13	10.9	12.7	14.5	18.0
0.62	7 7/16	0.474	0.97	1.48	1.93	3.81	5.68	7.53	9.37	11.2	13.0	14.8	18.5
0.63	7 9/16	0.485	0.99	1.51	1.98	3.91	5.82	7.72	6.61	11.5	13.4	15.2	19.0
0.64	7 11/16	0.497	1.02	1.55	2.03	4.01	5.97	7.91	9.85	11.8	13.7	15.6	19.5
0.65	7 13/16	0.509	1.04	1.59	2.08	4.11	6.12	8.11	10.1	12.1	14.1	16.0	19.9
0.66	7 15/16	0.522	1.07	1.63	2.13	4.20	6.26	8.31	10.3	12.4	14.4	16.4	20.4
0.67	8 1/16	0.534	1.10	1.66	2.18	4.30	6.41	8.51	10.6	12.7	14.8	16.8	20.9
0.68	8 3/16	0.546	1.12	1.70	2.23	4.40	6.56	8.71	10.9	13.0	15.1	17.2	21.5
0.69	8¼	0.558	1.15	1.74	2.28	4.50	6.71	8.91	11.1	13.3	15.5	17.6	22.0
0.70	8⅜	0.571	1.17	1.78	2.33	4.60	6.86	9.11	11.4	13.6	15.8	18.0	22.5
0.71	8½	0.584	1.20	1.82	2.38	4.70	7.02	9.32	11.6	13.9	16.2	18.5	23.0
0.72	8⅝	0.597	1.23	1.86	2.43	4.81	7.17	9.53	11.9	14.2	16.6	18.9	23.5
0.73	8¾	0.610	1.26	1.90	2.48	4.91	7.33	9.74	12.1	14.5	16.9	19.3	24.1
0.74	8⅞	0.623	1.28	1.94	2.53	5.02	7.49	9.95	12.4	14.9	17.3	19.7	24.6
0.75	9	....	1.31	1.98	2.58	5.12	7.65	10.2	12.7	15.2	17.7	20.1	25.1
0.76	9⅛	....	1.34	2.02	2.63	5.23	7.81	10.4	12.9	15.5	18.0	20.6	25.7
0.77	9¼	....	1.36	2.06	2.68	5.34	7.97	10.6	13.2	15.8	18.4	21.0	26.2
0.78	9⅜	....	1.39	2.10	2.74	5.44	8.13	10.8	13.5	16.2	18.8	21.5	26.8
0.79	9½	....	1.42	2.14	2.80	5.55	8.30	11.0	13.8	16.5	19.2	21.9	27.3
0.80	9⅝	....	1.45	2.18	2.85	5.66	8.46	11.3	14.0	16.8	19.6	22.4	27.9
0.81	9¾	....	1.48	2.22	2.90	5.77	8.63	11.5	14.3	17.2	20.0	22.8	28.5
0.82	9 13/16	....	1.50	2.27	2.96	5.88	8.79	11.7	14.6	17.5	20.4	23.3	29.0
0.83	9 15/16	....	1.53	2.31	3.02	6.00	8.96	11.9	14.9	17.8	20.8	23.7	29.6
0.84	10 1/16	....	1.56	2.35	3.07	6.11	9.13	12.2	15.2	18.2	21.2	24.2	30.2
0.85	10 3/16	....	1.59	2.39	3.12	6.22	9.30	12.4	15.5	18.5	21.6	24.6	30.8
0.86	10 5/16	....	1.62	2.44	3.18	6.33	9.48	12.6	15.8	18.9	22.0	25.1	31.4
0.87	10 7/16	....	1.65	2.48	3.24	6.44	6.65	12.8	16.0	19.2	22.4	25.6	31.9
0.88	10 9/16	....	1.68	2.52	3.29	6.56	9.82	13.1	16.3	19.6	22.8	26.1	32.5
0.89	10 11/16	....	1.71	2.57	3.35	6.68	10.0	13.3	16.6	19.9	23.2	26.5	33.1

TABLE 12—(Continued)

Upper head, *Ha*		Throat width											
Feet	Inches (approx.)	3 inches	6 inches	9 inches	1 foot	2 feet	3 feet	4 feet	5 feet	6 feet	7 feet	8 feet	10 feet
		Flow in cubic feet per second											
0.90	10 13/16	....	1.74	2.61	3.41	6.80	10.2	13.6	16.9	20.3	23.7	27.0	33.7
0.91	10 15/16	....	1.77	2.66	3.46	6.92	10.4	13.8	17.2	20.7	24.1	27.5	34.4
0.92	11 1/16	....	1.81	2.70	3.52	7.03	10.5	14.0	17.5	21.0	24.5	28.0	35.0
0.93	11 3/16	....	1.84	2.75	3.58	7.15	10.7	14.3	17.8	21.4	24.9	28.5	35.6
0.94	11¼	....	1.87	2.79	3.64	7.27	10.9	14.5	18.1	21.8	25.4	29.0	36.2
0.95	11⅜	....	1.90	2.84	3.70	7.39	11.1	14.8	18.4	22.1	25.8	29.5	36.8
0.96	11½	....	1.93	2.88	3.76	7.51	11.3	15.0	18.8	22.5	26.2	30.0	37.5
0.97	11⅝	....	1.97	2.93	3.82	7.63	11.4	15.3	19.1	22.9	26.7	30.5	38.1
0.98	11¾	....	2.00	2.98	3.88	7.75	11.6	15.5	19.4	23.2	27.1	31.0	38.7
0.99	11⅞	....	2.03	3.02	3.94	7.88	11.8	15.8	19.7	23.6	26.6	31.5	39.4
1.00	12	....	2.06	3.07	4.00	8.00	12.0	16.0	20.0	24.0	28.0	32.0	40.0
1.01	12⅛	....	2.09	3.12	4.06	8.12	12.2	16.3	20.3	24.4	28.4	32.5	40.7
1.02	12¼	....	2.12	3.17	4.12	8.25	12.4	16.5	20.6	24.8	28.9	33.0	41.3
1.03	12⅜	....	2.16	3.21	4.18	8.38	12.6	16.8	21.0	25.2	29.4	33.6	42.0
1.04	12½	....	2.19	3.26	4.25	8.50	12.8	17.0	21.3	25.6	29.8	34.1	42.6
1.05	12⅝	....	2.22	3.31	4.31	8.63	13.0	17.3	21.6	25.9	30.3	34.6	43.3
1.06	12¾	....	2.26	3.36	4.37	8.76	13.2	17.5	21.9	26.3	30.7	35.1	44.0
1.07	12 13/16	....	2.29	3.40	4.43	8.88	13.3	17.8	22.3	26.7	31.2	35.7	44.6
1.08	12 15/16	....	2.32	3.45	4.50	9.01	13.5	18.1	22.6	27.1	31.7	36.2	45.3
1.09	13 1/16	....	2.36	3.50	4.56	9.14	13.7	18.3	22.9	27.5	32.1	36.8	46.0
1.10	13 3/16	....	2.40	3.55	4.62	9.27	13.9	18.6	23.3	27.9	32.6	37.3	46.7
1.11	13 5/16	....	2.43	3.60	4.68	9.40	14.1	18.9	23.6	28.4	33.1	37.8	47.4
1.12	13 7/16	....	2.46	3.65	4.75	9.54	14.3	19.1	23.9	28.8	33.6	38.4	48.0
1.13	13 9/16	....	2.50	3.70	4.82	9.67	14.5	19.4	24.3	29.2	34.1	38.9	48.7
1.14	13 11/16	....	2.53	3.75	4.88	9.80	14.7	19.7	24.6	29.6	34.5	39.5	49.4
1.15	13 13/16	....	2.57	3.80	4.94	9.94	14.9	19.9	25.0	30.0	35.0	40.1	50.1
1.16	13 15/16	....	2.60	3.85	5.01	10.1	15.1	20.2	25.3	30.4	35.5	40.6	50.8
1.17	14 1/16	....	2.64	3.90	5.08	10.2	15.3	20.5	25.7	30.8	36.0	41.2	51.6
1.18	14 3/16	....	2.68	3.95	5.15	10.3	15.6	20.8	26.0	31.3	36.5	41.8	52.3
1.19	14¼	....	2.71	4.01	5.21	10.5	15.8	21.1	26.4	31.7	37.0	42.3	53.0
1.20	14⅜	....	2.75	4.06	5.28	10.6	16.0	21.3	26.7	32.1	37.5	42.9	53.7
1.21	14½	....	2.78	4.11	5.34	10.8	16.2	21.6	27.1	32.5	38.0	43.5	54.4
1.22	14⅝	....	2.82	4.16	5.41	10.9	16.4	21.9	27.4	33.0	38.5	44.1	55.2
1.23	14¾	....	2.86	4.22	5.48	11.0	16.6	22.2	27.8	33.4	39.0	44.6	55.9
1.24	14⅞	....	2.89	4.27	5.55	11.2	16.8	22.5	28.1	33.8	39.5	45.2	56.6
1.25	15	....	....	4.32	5.62	11.3	17.0	22.8	28.5	34.3	40.0	45.8	57.4
1.26	15⅛	....	....	4.37	5.69	11.5	17.2	23.0	28.9	34.7	40.5	46.4	58.1
1.27	15¼	....	....	4.43	5.76	11.6	17.4	23.3	29.2	35.1	41.1	47.0	58.9
1.28	15⅜	....	....	4.48	5.82	11.7	17.7	23.6	29.6	35.6	41.6	47.6	59.6
1.29	15½	....	....	4.53	5.89	11.9	17.9	23.9	30.0	36.0	42.1	48.2	60.4

TABLE 12—(Continued)

Upper head, *Ha* Feet	Inches (approx.)	3 inches	6 inches	9 inches	1 foot	2 feet	3 feet	4 feet	5 feet	6 feet	7 feet	8 feet	10 feet
		Flow in cubic feet per second											
1.30	15½	....	....	4.50	5.96	12.0	18.1	24.2	30.3	36.5	42.6	48.8	61.1
1.31	15¾	....	....	4.64	6.03	12.2	18.3	24.5	30.7	36.9	43.1	49.4	61.9
1.32	15 13/16	....	....	4.69	6.10	12.3	18.5	24.8	31.1	37.4	43.7	50.0	62.7
1.33	15 15/16	....	....	4.75	6.18	12.4	18.8	25.1	31.4	37.8	44.2	50.6	63.4
1.34	16 1/16	....	....	4.80	6.25	12.6	19.0	25.4	31.8	38.3	44.7	51.2	64.2
1.35	16 3/16	....	....	4.86	6.32	12.7	19.2	25.7	32.2	38.7	45.3	51.8	65.0
1.36	16 5/16	....	....	4.92	6.39	12.9	19.4	26.0	32.6	39.2	45.8	52.5	65.7
1.37	16 7/16	....	....	4.97	6.46	13.0	19.6	26.3	33.0	39.7	46.4	53.1	66.5
1.38	16 9/16	....	....	5.03	6.53	13.2	19.9	26.6	33.3	40.1	46.9	53.7	67.3
1.39	16 11/16	....	....	5.08	6.60	13.3	20.1	26.9	33.7	40.6	47.4	54.3	68.1
1.40	16 13/16	....	....	....	6.68	13.5	20.3	27.2	34.1	41.1	48.0	55.0	68.9
1.41	16 15/16	....	....	....	6.75	13.6	20.6	27.5	34.5	41.5	48.5	55.6	69.7
1.42	17 1/16	....	....	....	6.82	13.8	20.8	27.8	34.9	42.0	49.1	56.2	70.5
1.43	17 3/16	....	....	....	6.89	13.9	21.0	28.1	35.3	42.5	49.6	56.9	71.3
1.44	17¼	....	....	....	6.97	14.1	21.2	28.5	35.7	42.9	50.2	57.5	72.1
1.45	17⅜	....	....	....	7.04	14.2	21.3	28.8	36.1	43.4	50.8	58.1	72.9
1.46	17½	....	....	....	7.12	14.4	21.7	29.1	36.5	43.9	51.3	58.8	73.7
1.47	17⅝	....	....	....	7.19	14.5	21.9	29.4	36.9	44.4	51.9	59.4	74.6
1.48	17¾	....	....	....	7.26	14.7	22.2	29.7	37.3	44.9	52.4	60.1	75.4
1.49	17⅞	....	....	....	7.34	14.9	22.4	30.0	37.7	45.3	53.0	60.7	76.2
1.50	18	....	....	....	7.41	15.0	22.6	30.3	38.1	45.8	53.6	61.4	77.0
1.51	18⅛	....	....	....	7.49	15.2	22.9	30.7	38.5	46.3	54.2	62.1	77.9
1.52	18¼	....	....	....	7.57	15.3	23.1	31.0	38.9	46.8	54.7	62.7	78.7
1.53	18⅜	....	....	....	7.64	15.5	23.4	31.3	39.3	47.3	55.3	63.4	79.5
1.54	18½	....	....	....	7.72	15.6	23.6	31.6	39.7	47.8	55.9	64.0	80.4
1.55	18⅝	....	....	....	7.80	15.8	23.8	32.0	40.1	48.3	56.5	64.7	81.2
1.56	18¾	....	....	....	7.87	15.9	24.1	32.3	40.5	48.8	57.1	65.4	82.1
1.57	18 13/16	....	....	....	7.95	16.1	24.3	32.6	40.9	49.3	57.7	66.1	82.9
1.58	18 15/16	....	....	....	8.02	16.3	24.6	32.9	41.4	49.8	58.2	66.7	83.8
1.59	19 1/16	....	....	....	8.10	16.4	24.8	33.3	41.8	50.3	58.8	67.4	84.6
1.60	19 3/16	....	....	....	8.18	16.6	25.1	33.6	42.2	50.8	59.4	68.1	85.5
1.61	19 5/16	....	....	....	8.26	16.7	25.3	33.9	42.6	51.3	60.0	68.8	86.4
1.62	19 7/16	....	....	....	8.34	16.9	25.5	34.3	43.0	51.8	60.6	69.5	87.2
1.63	19 9/16	....	....	....	8.42	17.1	25.8	34.6	43.4	52.3	61.2	70.2	88.1
1.64	19 11/16	....	....	....	8.49	17.2	26.0	34.9	43.9	52.8	61.8	70.9	89.0
1.65	19 13/16	....	....	....	8.57	17.4	26.3	35.3	44.3	53.3	62.4	71.6	89.9
1.66	19 15/16	....	....	....	8.65	17.6	26.5	35.6	44.7	53.9	63.0	72.3	90.7
1.67	20 1/16	....	....	....	8.73	17.7	26.8	35.9	45.1	54.4	63.6	73.0	91.6
1.68	20 3/16	....	....	....	8.81	17.9	27.0	36.3	45.6	54.9	64.3	73.7	92.5
1.69	20¼	....	....	....	8.89	18.0	27.3	36.6	46.0	55.4	64.9	74.4	93.4

TABLE 12—(Continued)

Upper head, *Ha*		Throat width											
Feet	Inches (ap-prox.)	3 inches	6 inches	9 inches	1 foot	2 feet	3 feet	4 feet	5 feet	6 feet	7 feet	8 feet	10 feet
		Flow in cubic feet per second											
1.70	20⅜	......	......	......	8.97	18.2	27.6	37.0	46.4	56.0	65.5	75.1	94.3
1.71	20½	......	......	......	9.05	18.4	27.8	37.3	46.9	56.5	66.1	75.8	95.2
1.72	20⅝	......	......	......	9.13	18.5	28.1	37.7	47.3	57.0	66.7	76.5	96.1
1.73	20¾	......	......	......	9.21	18.7	28.3	38.0	47.7	57.5	67.3	77.2	97.0
1.74	20⅞	......	......	......	9.29	18.9	28.6	38.3	48.2	58.1	68.0	77.9	97.9
1.75	21	......	......	......	9.38	19.0	28.8	38.7	48.6	58.6	68.6	78.7	98.8
1.76	21⅛	......	......	......	9.46	19.2	29.1	39.0	49.1	59.1	69.2	79.4	99.7
1.77	21¼	......	......	......	9.54	19.4	29.3	39.4	49.5	59.7	69.9	80.1	100.6
1.78	21⅜	......	......	......	9.62	19.6	29.6	39.7	49.9	60.2	70.5	80.8	101.5
1.79	21½	......	......	......	9.70	19.7	29.9	40.1	50.4	60.7	71.1	81.6	102.4
1.80	21⅝	......	......	......	9.79	19.9	30.1	40.5	50.8	61.3	71.8	82.3	103.4
1.81	21¾	......	......	......	9.87	20.1	30.4	40.8	51.3	61.8	72.4	83.0	104.4
1.82	21 13/16	......	......	......	9.95	20.2	30.7	41.2	51.7	62.4	73.0	83.8	105.3
1.83	21 15/16	......	......	......	10.0	20.4	30.9	41.5	52.2	62.9	73.7	84.5	106.2
1.84	22 1/16	......	......	......	10.1	20.6	31.2	41.9	52.6	63.5	74.3	85.3	107.1
1.85	22 3/16	......	......	......	10.2	20.8	31.5	42.2	53.1	64.0	75.0	86.0	108.1
1.86	22 5/16	......	......	......	10.3	29.9	31.7	42.6	53.6	64.6	75.6	86.8	109.0
1.87	22 7/16	......	......	......	10.4	21.1	32.0	43.0	54.0	65.1	76.3	87.5	110.0
1.88	22 9/16	......	......	......	10.5	21.3	32.3	43.3	54.5	65.7	76.9	88.3	110.9
1.89	22 11/16	......	......	......	10.5	21.5	32.5	43.7	54.9	66.3	77.6	89.0	111.9
1.90	22 13/16	......	......	......	10.6	21.6	32.8	44.1	55.4	66.8	78.2	89.8	112.9
1.91	22 15/16	......	......	......	10.7	21.8	33.1	44.4	55.9	67.4	78.9	90.5	113.8
1.92	23 1/16	......	......	......	10.8	22.0	33.3	44.8	56.3	67.9	79.6	91.3	114.8
1.93	23 3/16	......	......	......	10.9	22.2	33.6	45.2	56.8	68.5	80.2	92.1	115.8
1.94	23¼	......	......	......	11.0	22.4	33.9	45.5	57.3	69.1	80.9	92.8	116.7
1.95	23⅜	......	......	......	11.1	22.5	34.1	45.9	57.7	69.6	81.6	93.6	117.7
1.96	23½	......	......	......	11.1	22.7	34.4	46.3	58.2	70.2	82.2	94.4	118.7
1.97	23⅝	......	......	......	11.2	22.9	34.7	46.6	58.7	70.8	82.9	95.1	119.7
1.98	23¾	......	......	......	11.3	23.1	35.0	47.0	59.1	71.4	83.6	95.9	120.6
1.99	23⅞	......	......	......	11.4	23.2	35.3	47.4	59.6	71.9	84.3	96.7	121.6
2.00	24	......	......	......	11.5	23.4	35.5	47.8	60.1	72.5	84.9	97.5	122.6
2.01	24⅛	......	......	......	11.6	23.6	35.8	48.1	60.6	73.1	85.6	98.3	123.6
2.02	24¼	......	......	......	11.7	23.8	36.1	48.5	61.0	73.7	86.3	99.1	124.6
2.03	24⅜	......	......	......	11.8	24.0	36.4	48.9	61.5	74.2	87.0	99.8	125.6
2.04	24½	......	......	......	11.8	24.2	36.7	49.3	62.0	74.8	87.7	100.6	126.6
2.05	24⅝	......	......	......	11.9	24.3	36.9	49.7	62.5	75.4	88.4	101.4	127.6
2.06	24¾	......	......	......	12.0	24.5	37.2	50.1	63.0	76.0	89.1	102.2	128.6
2.07	24 13/16	......	......	......	12.1	24.7	37.5	50.4	63.5	76.6	89.8	103.0	129.6
2.08	24 15/16	......	......	......	12.2	24.9	37.8	50.8	63.9	77.2	90.4	103.8	130.6
2.09	25 1/16	......	......	......	12.3	25.1	38.1	51.2	64.4	77.8	91.1	104.6	131.6

TABLE 12—(Continued)

Upper head, Ha		Throat width											
Feet	Inches (approx.)	3 inches	6 inches	9 inches	1 foot	2 feet	3 feet	4 feet	5 feet	6 feet	7 feet	8 feet	10 feet
		Flow in cubic feet per second											
2.10	25 3/16	......	......	......	12.4	25.3	38.4	51.6	64.9	78.4	91.8	105.4	132.7
2.11	25 5/16	......	......	......	12.5	25.5	38.6	52.0	65.4	79.0	92.5	106.2	133.7
2.12	25 7/16	......	......	......	12.6	25.6	38.9	52.4	65.9	79.6	93.3	107.0	134.7
2.13	25 9/16	......	......	......	12.6	25.8	39.2	52.8	66.4	80.2	94.0	107.9	135.7
2.14	25 11/16	......	......	......	12.7	26.0	39.5	53.2	66.9	80.8	94.7	108.7	136.8
2.15	25 13/16	......	......	......	12.8	26.2	39.8	53.5	67.4	81.4	95.4	109.5	137.8
2.16	25 15/16	......	......	......	12.9	26.4	40.1	53.9	67.9	82.0	96.1	110.3	138.8
2.17	26 1/16	......	......	......	13.0	26.6	40.4	54.3	68.4	82.6	96.8	111.1	139.9
2.18	26 3/16	......	......	......	13.1	26.8	40.7	54.7	68.9	83.2	97.5	111.9	140.9
2.19	26¼	......	......	......	13.2	27.0	41.0	55.1	69.4	83.8	98.2	112.8	142.0
2.20	26⅜	......	......	......	13.3	27.2	41.3	55.5	69.9	84.4	98.9	113.6	143.0
2.21	26½	......	......	......	13.4	27.3	41.5	55.9	70.4	85.0	99.7	114.4	144.1
2.22	26⅝	......	......	......	13.5	27.5	41.8	56.3	70.9	85.6	100.0	115.3	145.1
2.23	26¾	......	......	......	13.6	27.7	42.1	56.7	71.4	86.3	101.1	116.1	146.2
2.24	26⅞	......	......	......	13.7	27.9	42.4	57.1	71.9	86.9	101.8	116.9	147.3
2.25	27	......	......	......	13.7	28.1	42.7	57.5	72.4	87.5	102.6	117.8	148.3
2.26	27⅛	......	......	......	13.8	28.3	43.0	57.9	72.9	88.1	103.3	118.6	149.4
2.27	27¼	......	......	......	13.9	28.5	43.3	58.3	73.5	88.7	104.0	119.5	150.5
2.28	27⅜	......	......	......	14.0	28.7	43.6	58.7	74.0	89.4	104.8	120.3	151.5
2.29	27½	......	......	......	14.1	28.9	43.9	59.2	74.5	90.0	105.5	121.2	152.6
2.30	27⅝	......	......	......	14.2	29.1	44.2	59.6	75.0	90.6	106.2	122.0	153.7
2.31	27¾	......	......	......	14.3	29.3	44.5	60.0	75.5	91.2	107.0	122.9	154.8
2.32	27 13/16	......	......	......	14.4	29.5	44.8	60.4	76.0	91.9	107.7	123.7	155.8
2.33	27 15/16	......	......	......	14.5	29.7	45.1	60.8	76.6	92.5	108.5	124.6	156.9
2.34	28 1/16	......	......	......	14.6	29.9	45.4	61.2	77.1	93.1	109.2	125.4	158.0
2.35	28 3/16	......	......	......	14.7	30.1	45.7	61.6	77.6	93.8	110.0	126.3	159.1
2.36	28 5/16	......	......	......	14.8	30.3	46.0	62.0	78.1	94.4	110.7	127.2	160.2
2.37	28 7/16	......	......	......	14.9	30.5	46.4	62.4	78.7	95.1	111.5	128.0	161.3
2.38	28 9/16	......	......	......	15.0	30.7	46.7	62.9	79.2	95.7	112.2	128.9	162.4
2.39	28 11/16	......	......	......	15.1	30.9	47.0	63.3	79.7	96.3	113.0	129.8	163.5
2.40	28 13/16	......	......	......	15.2	31.1	47.3	63.7	80.3	97.0	113.7	130.7	164.6
2.41	28 15/16	......	......	......	15.3	31.3	47.6	64.1	80.8	97.6	114.5	131.5	165.7
2.42	29 1/16	......	......	......	15.4	31.5	47.9	64.5	81.3	98.3	115.3	132.4	166.8
2.43	29 3/16	......	......	......	15.5	31.7	48.2	65.0	81.8	98.9	116.0	133.3	167.9
2.44	29¼	......	......	......	15.6	31.9	48.5	65.4	82.4	99.6	116.8	134.2	169.1
2.45	29⅜	......	......	......	15.6	32.1	48.8	65.8	82.9	100.2	117.6	135.1	170.2
2.46	29½	......	......	......	15.7	32.3	49.1	66.2	83.5	100.9	118.3	135.9	171.3
2.47	29⅝	......	......	......	15.9	32.5	49.5	66.7	84.0	101.5	119.1	136.8	172.4
2.48	29¾	......	......	......	15.9	32.7	49.8	67.1	84.5	102.2	119.9	137.7	173.6
2.49	29⅞	......	......	......	16.0	32.9	50.1	67.5	85.1	102.8	120.6	138.6	174.7
2.50	30	......	......	......	16.1	33.1	50.4	67.9	85.6	103.5	121.4	139.5	175.8

3-INCH PARSHALL FLUME

DISCHARGE FORMULA: $Q = 0.992 H_A^{1.547}$

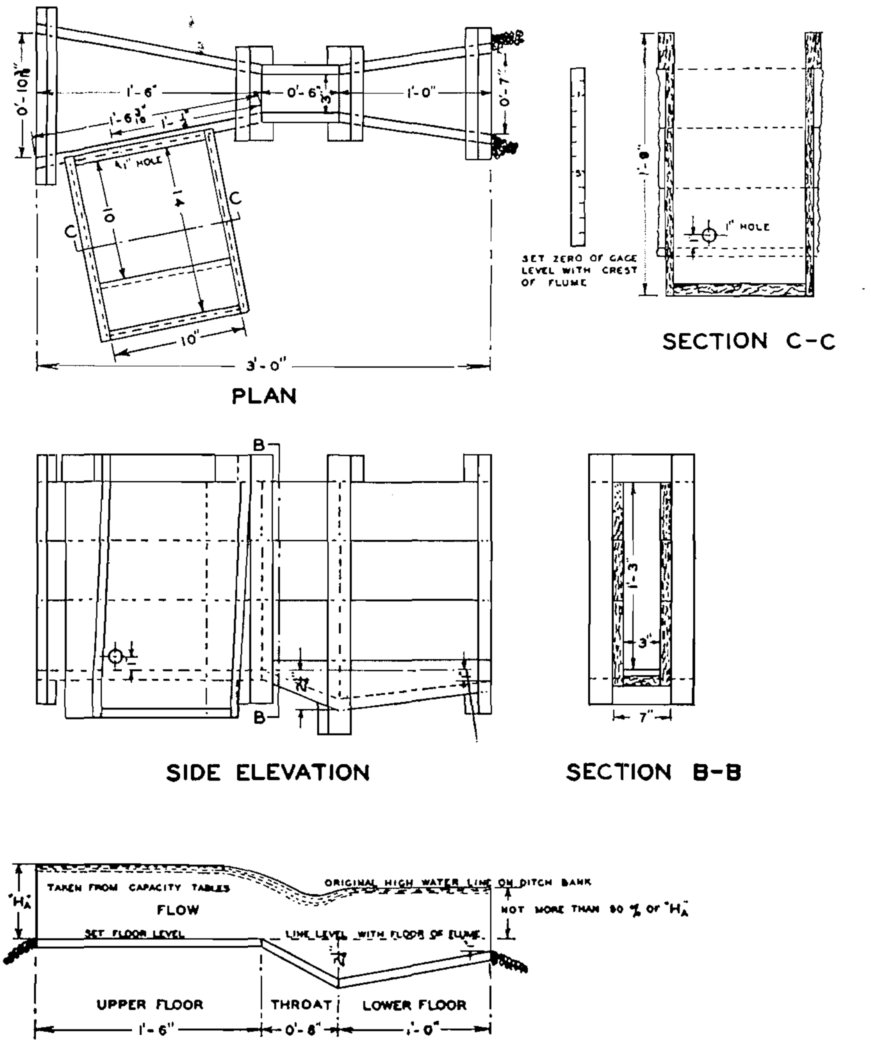


Fig. 25. Plans for 3-inch Parshall flume.

Plans—Detail drawings showing all dimensions are given in figures 25 to 28, inclusive, for flumes of throat widths from 3 inches to 1 foot. These drawings are for wooden flumes, but the same inside dimensions hold whether

TABLE 13—Bills of material for 3-inch to 1-foot wooden Parshall flumes.

Item	No. of Pcs.	3-inch	No. of Pcs.	6-inch	No. of Pcs.	9-inch	No. of Pcs.	1-foot
Upper side walls	2	1"x10x1'6⅜"	4	1"x10"x2'7/16"	2	2"x10"x2'10⅝"	2	2"x10"x4'6"
	2	1"x 8x1'6⅜"			4	2"x 8"x2'10⅝"	4	2"x 8"x4'6"
Throat side walls	4	1"x 8"x0'6"	1	1"x 6"x1'0"	6	2"x 8"x1'0"	4	2"x 8"x2'0"
	1	1"x 4"x0'6"	4	1"x10"x1'0"	1	2"x 8"x1'0"	3	2"x10"x2'0"
Lower side walls	2	1"x 8"x1'0½"	2	1"x10"x2'0½"	2	2"x10"x1'6½"	4	2"x10"x3'0½"
	4	1"x 6"x1'0½"	4	1"x 8"x2'0½"	4	2"x 8"x1'6½"	3	2"x 8"x3'0½"
					1	2"x 6"x1'6½"		
Wall posts	6	2"x 4"x2'2"	2	2"x 4"x2'9"	4	2"x 4"xx3'0"	6	2"x 4"x3'0"
	2	2"x 4"x2'4"	4	2"x 4"x2'4"	2	4"x 4"x3'6"	2	4"x 4"x4'0"
			2	2"x 4"x2'7"	2	4"x 4"x3'0 "	2	4"x 4"x3'0"
Cross ties	4	2"x 4"x1'1"	4	2"x 4"x2'2"	2	2"x 4"x3'0"	2	2"x 4"x4'0"
	2	2"x 4"x1'6"	4	2"x 4"x1'4"	2	2"x 4"x2'3"	4	2"x 4"x3'0"
	2	2"x 4"x1'9"			4	2"x 4"x1'9"	4	2"x 4"x2'0"
Stilling box								
Sides	4	1"x 8"x1'9"	4	1"x 8"x2'3"	4	1"x 8"x3'0"	4	1"x 8"x3'0"
End	1	1"x10"x2'0"	1	1"x10"x2'4"	1	1"x10"x3'1"	1	1"x10"x3'1"
Bottom	1	2"x10"x1'2"	1	2"x10"x1'2"	1	2"x10"x1'2"	1	2"x10"x1'2"
Lid	1	1"x12"x1'6"	1	1"x12"x1'6"	1	1"x12"x1'6"	1	1"x12"x1'6"
Nailing strip	2	2"x 4"x2'0"	2	2"x 4"x2'0"	2	2"x 4"x2'0"	2	2"x 4"x2'0"
Upper floor	2	2"x 4"x1'6"	2	2"x 6"x2'7/16"	1	2"x 8"x2'10"	2	2"x12"x4'5"
					1	2"x10"x2'10"		
Throat floor	1	2"x 4"x0'6"	1	2"x 6"x1'0"	1	2"x10"x1'0"	1	2"x12"x2'0"
Lower floor	2	2"x 4"x1'0"	2	2"x 7"x2'0"	1	2"x 4"x1'6"	1	2"x 6"x3'0"
					1	2"x10"x1'6"	1	2"x12"x3'0"
Bolts	20	¼"x3"	20	¼"x3"	20	⅜"x4"	20	⅜"x4"
Cut washer	20		20		20		20	
Nails		3 lbs.-16d		4 lbs.-16d		7 lbs.-16d		8 lbs.-16d
		3 lbs.-10d		4 lbs.-10d		2 lbs.-10d		2 lbs.-10d
Total board feet of lumber		44		65		117		189

the flume is made from lumber, concrete, or metal. Table 13 gives detailed bills of material for 3-inch, 6-inch, 9-inch, and 1-foot wooden Parshall flumes, respectively, together with the total number of board feet required for each.

6-INCH PARSHALL FLUME

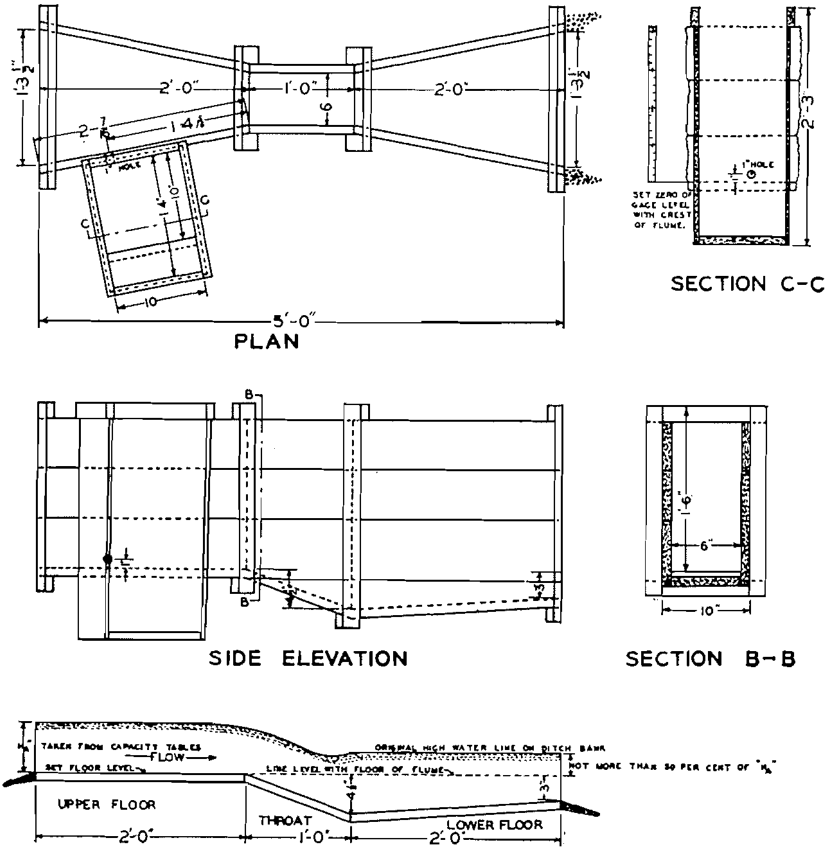
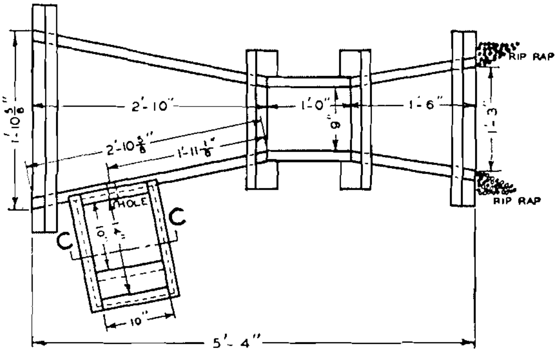


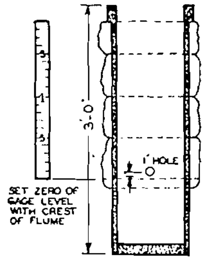
Fig. 26. Plans for 6-inch Parshall flume.

Forms—Frequently irrigation companies wish to install a number of concrete Parshall flumes of a particular size. If the number to be installed is large, it is desirable to have one or more portable forms for placing the concrete rather than constructing forms in place each time. Many soil conservation districts have such forms that can be borrowed or rented by individuals

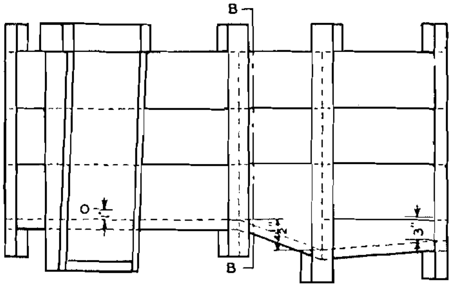
9-INCH PARSHALL FLUME



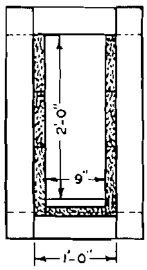
PLAN



SECTION C-C



SIDE ELEVATION



SECTION B-B

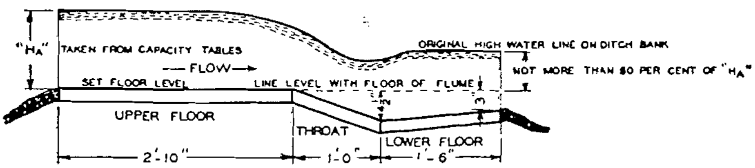


Fig. 27. Plans for 9-inch Parshall flume.

1-FOOT PARSHALL FLUME

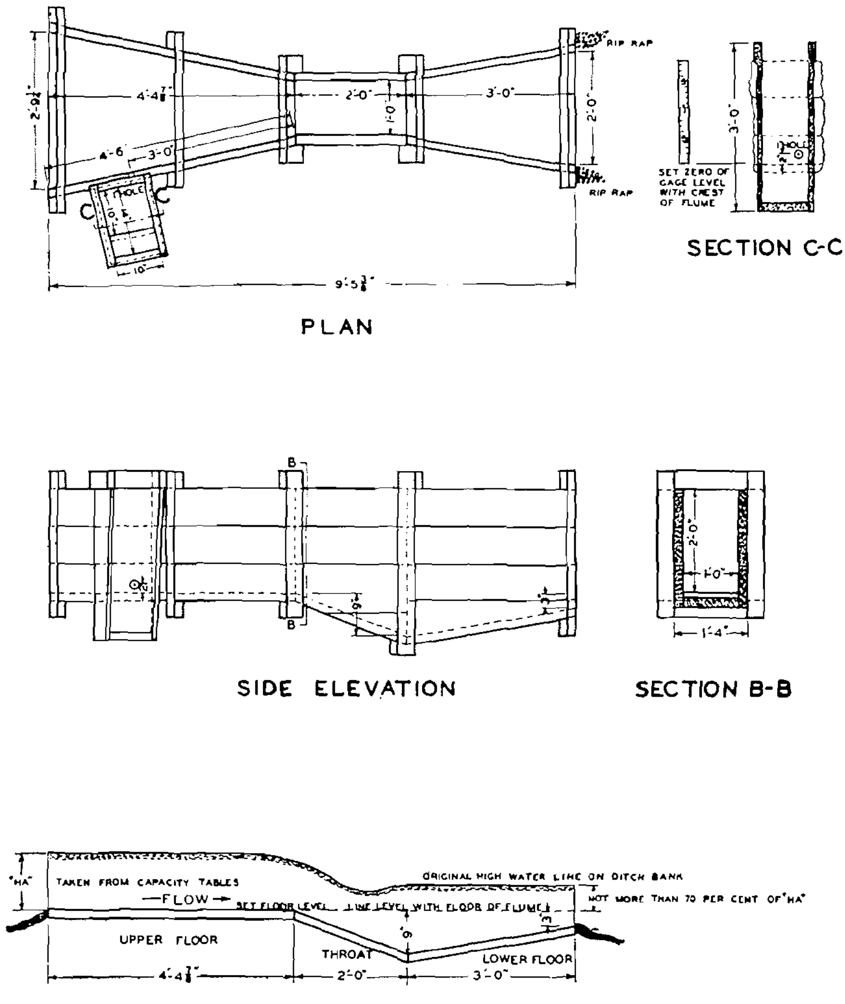


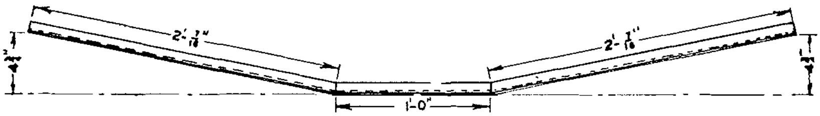
Fig. 28. Plans for 1-foot Parshall flume.

or companies. The plans and specifications for the forms of a 6-inch concrete Parshall flume are shown in Figure 29. These forms are made from 12-gauge galvanized iron and reinforced with angles. There are a total of seven separate pieces: two templates for placing the floor, two pieces for the outside walls, and three separate pieces for the inside walls. No provision is made for the stilling well, which may be poured separately.

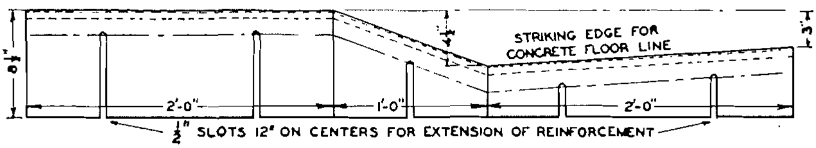
PORTABLE STEEL FORM FOR 6-INCH CONCRETE PARSHALL FLUME

TEMPLATES FOR FLOOR

RIGHT AND LEFT SIDES



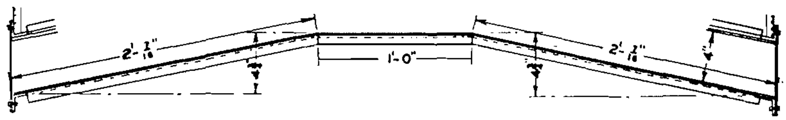
PLAN (LEFT TEMPLATE SHOWN ONLY)



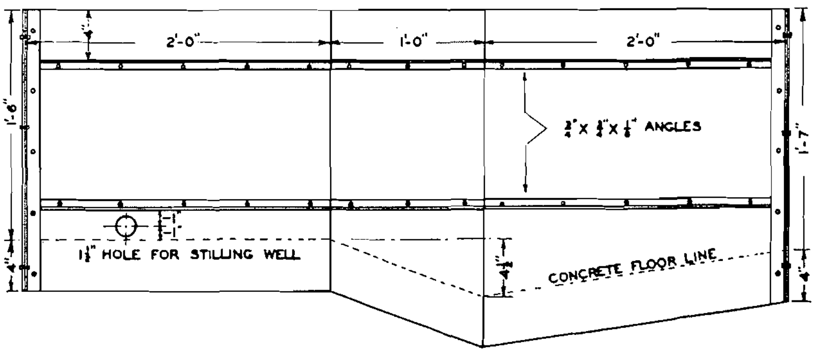
ELEVATION

OUTSIDE FORMS FOR WALLS

TWO SECTIONS RIGHT AND LEFT SIDES



PLAN (RIGHT SIDE SHOWN ONLY)



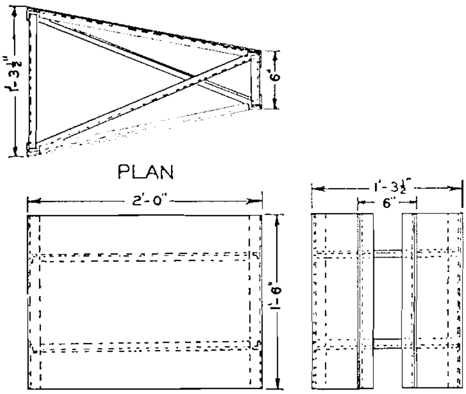
ELEVATION

Sheet 1 of 2 Sheets

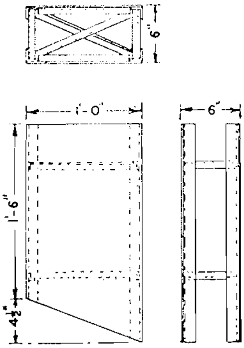
Fig. 29. Forms for 6-inch concrete Parshall flume.

PARSHALL FLUME FORMS—(Continued)

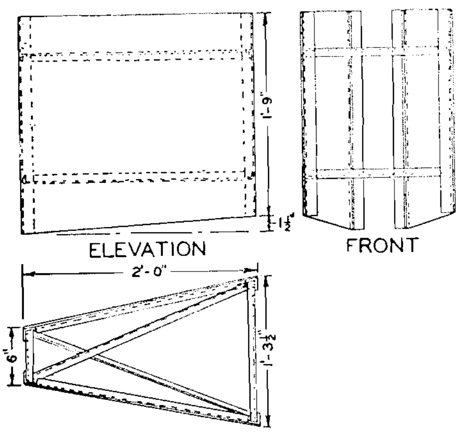
INSIDE FORM FOR
UPPER CONVERGING SECTION



INSIDE FORM FOR
MIDDLE SECTION



INSIDE FORM FOR
LOWER DIVERGING SECTION



SPECIFICATIONS

USE:
12 GAGE GALVANIZED IRON PLATE
$1\frac{1}{4}$" x $1\frac{1}{4}$" x $\frac{1}{8}$" ANGLES ON ALL
EDGES WHERE BOLTING TOGETHER
OF FORM IS NECESSARY
$\frac{3}{4}$" x $\frac{3}{4}$" x $\frac{1}{8}$" FOR ALL OTHERS
$\frac{3}{16}$" RIVETS
$\frac{1}{4}$" BOLTS FOR JOINING FORMS

SHEET 2 OF 2 SHEETS

Fig. 29. Forms for 6-inch concrete Parshall flume. (Cont.)

The two templates for the floor are placed to elevation with the reinforcing bars in place for the floor and protruding through the slots of the templates on either side. The floor is then poured, using the templates as a guide to strike off the concrete to the proper shape. While the concrete is still partially green the templates are removed and the reinforcing bars bent up through the concrete for reinforcing the walls. The remaining parts of the form are then put in place and securely bolted together. A pipe is placed in to lead to the stilling well and the walls poured.

DIVIDERS

Many irrigation companies in Utah divide their streams according to the number of shares of stock owned by individuals or groups of individuals. On the smaller streams either a single company owns the entire flow or it is divided among two or three companies, each company owning a share of the total stream. The users are not so much interested in the measurement of the water as they are in the division of the stream. For example, one company may be entitled to 5/12 of the stream and another company to 7/12 of the stream. The two companies own all the water in the stream. They are not particularly interested in the quantity, but they are interested in the division. Sometimes a divsion must be made where it is impractical to make a measurement.

If even an approximate division is made, a few principles must be observed. The water must approach the divider in parallel paths; there must

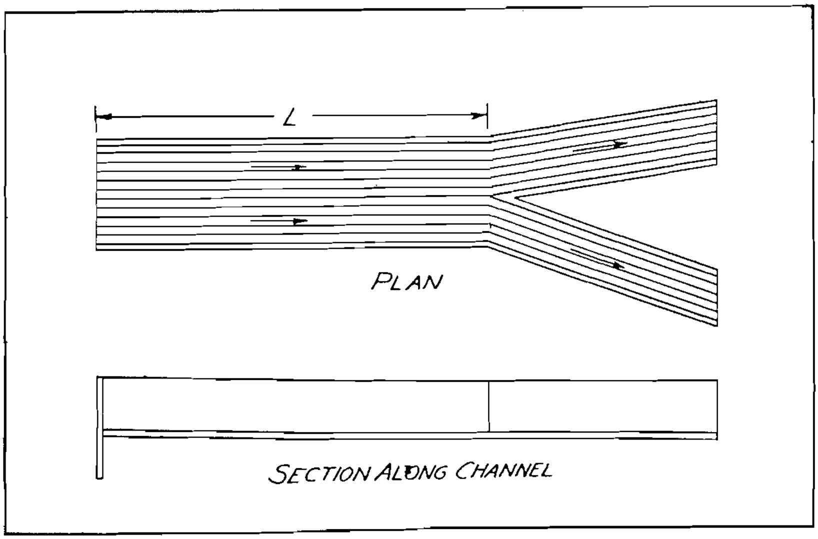


Fig. 30. Typical divider used on streams carrying considerable sand and gravel.

be no cross currents. To secure this condition, the divider box must be placed at the lower end of a long flume or of a straight open channel. The floor of the channel immediately above the divider should be level transversely. If the water is reasonably free from silt it is desirable to have the water approach the divider at a low velocity. For streams carrying considerable silt and gravel there should be no obstruction in the channel in the form of bulkhead, and the velocity with which the water enters should be maintained through the structure. Figure 30 shows a form of divider used on mountain streams which carry considerable sand and gravel. It is very important that these structures have a long straight channel of approach and that the floor be level transversely. Any gravel or debris allowed to collect in the channel of approach causes cross currents and interferes with proper division.

The flow over a weir can be easily divided by placing a sharp-edged partition below the weir to divide the stream as it falls over the crest. The crest of this partition should be placed a sufficient distance below the weir crest to permit a free circulation of air between the divider and the sheet of water falling over the weir.

The discharge over a weir is not exactly proportional to the length of the crest; however, the error in considering it so is slight. The trapezoidal weir is the most desirable form if it is to be used as a divider. The flow over this weir is very nearly proportional to length of the crest. If it is desired to divide the stream into two parts, one taking five-sixths and the other one-sixth of the flow, the divider should be placed one-sixth of the distance from the end of the weir. Figure 31 shows a trapezoidal weir divider fixed to divide a stream into three parts.

An appropriate measuring device should be installed in all streams below a divider to insure proper division.

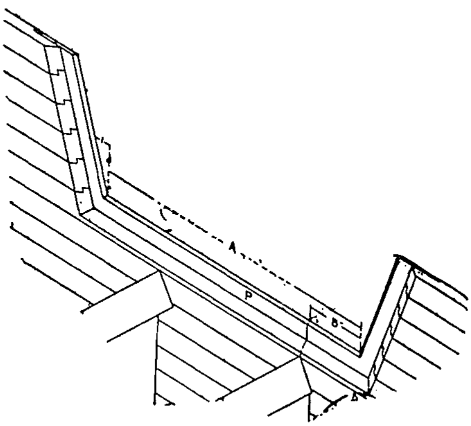


Fig. 31. Divider below trapezoidal weir.

MEASURING DISCHARGE FROM PIPES

Frequently the discharge from an artesian well or from a pumping plant is desired when there are no facilities for making a measurement by methods in common use. For such measurements coordinate methods[9] of measuring pipe flow have been suggested. However, these methods have limited accuracy and should not be used where accuracy is essential or where some other method can be conveniently used.

These methods consist of measuring the coordinates of a point in the jet issuing from the end of the pipe; the chief difficulty is in accurately measuring the coordinates. The flow from pipes may be measured whether the pipe is discharging vertically upward, horizontally, or at some angle with the horizontal. Usually discharge pipes from artesian wells or pumping plants are

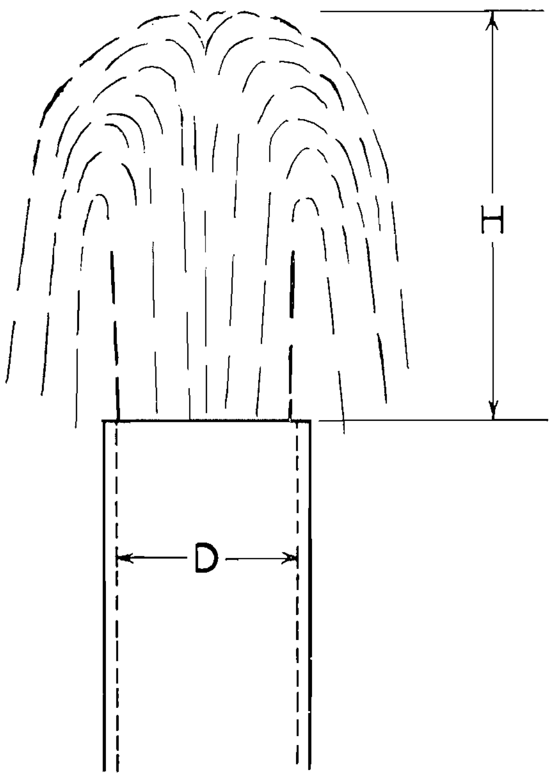


Fig. 32. (a) Drawing showing dimensions necessary in making a measurement of the flow from vertical pipes.

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[9]Christiansen, J. E., "Coordinate Methods of Measuring Pipe Flow." Mimeographed report of Division of Irrigation Investigations and Practice, University of California.

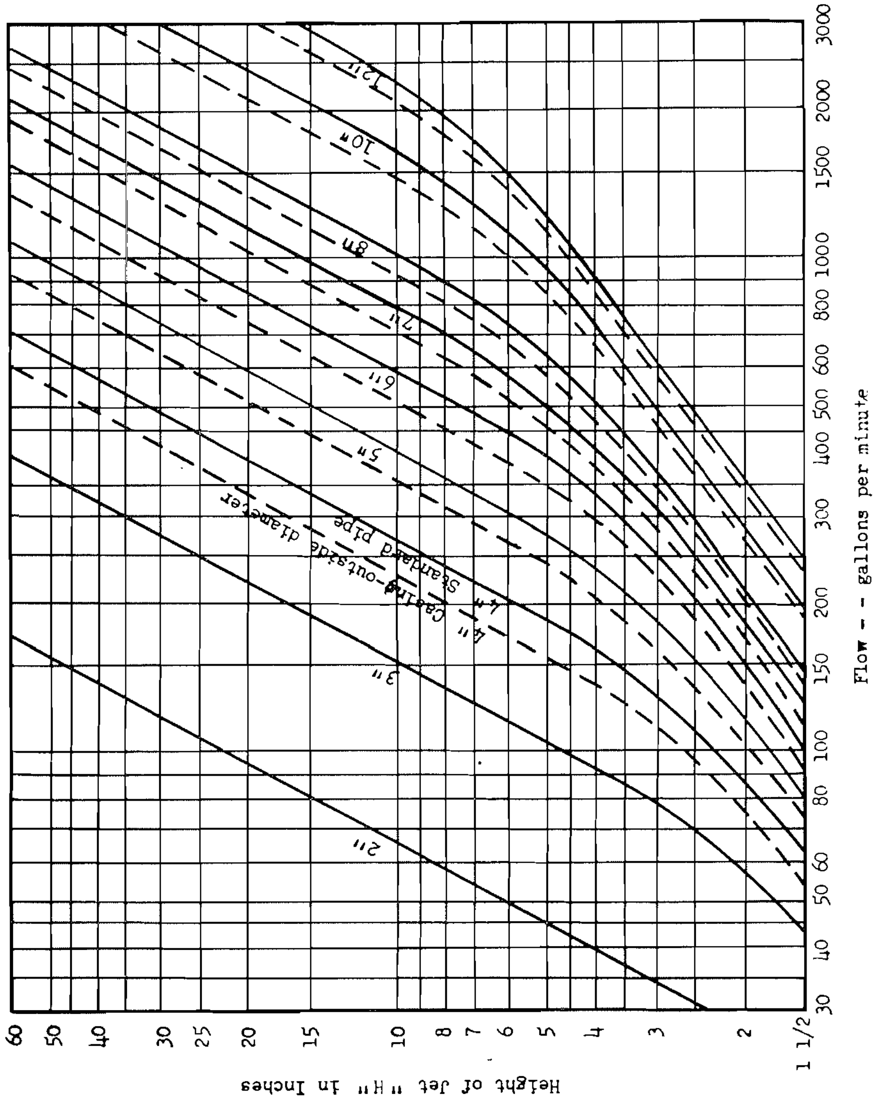

Fig. 33. Discharge curves for measurement of flow from vertical pipes. Based on data from experiments of Lawrence and Braunworth. Am. Soc., C. E. Trans. (57) 1906.

either vertical or horizontal and therefore only these two cases will be discussed here.

Vertical Pipes. Lawrence and Braunworth[10] conducted an extensive set of experiments to determine the flow from vertical pipes. They found that when the height of the jet exceeds 1.4 D, as determined by sighting over the jet to obtain the maximum rise, the flow can be expressed by the empirical equation:

$$G.P.M. = 5.01\ D^{1.99}\ H^{0.53}$$

When the height of the jet is less than 0.37 D, the flow is similar to that over a weir and can be expressed by the equation:

$$G.P.M. = 6.17\ D^{1.25}\ H^{1.35}$$

in which G.P.M. is flow in gallons per minute; D is the diameter of the pipe in inches; and H is the height of the jet in inches.

For jet heights between 0.37 D and 1.4 D the flow is somewhat less than that given by either of these equations.

Figure 33 shows the flow in gallons per minute for pipe and casing 2 to 12 inches in diameter, for jet heights, H, from 1½ to 60 inches. This diagram was prepared from Lawrence and Braunworth's data, using the actual inside diameter of standard pipe and casing as given in pipe handbooks.

Horizontal Pipes. For pipes discharging horizontally, it is necessary to measure both a horizontal and a vertical distance from some point on the end of the pipe to a similar point in the jet. These horizontal and vertical distances are called the X and Y ordinates, respectively. In the method described by Slichter, the ordinates are measured from the center of the end of the pipe to the center of the jet, as shown in Figure 34. The expression for the flow from completely filled pipes is derived in the following manner: The distance Y that a particle falls in time, t, after issuing from the end of a horizontal pipe is

$$Y = \frac{g\ t^2}{2}$$

and the horizontal distance X it travels is

$$X = V\ t \quad \text{where V is the}$$

initial horizontal velocity. Combining these equations by eliminating t and solving for V, we obtain:

$$V = \frac{X\sqrt{g}}{\sqrt{2\ Y}}$$

from which we obtain the expression for the flow in cubic feet per second, all dimensions being in feet:

[10]Lawrence, F. E., and P. L. Braunworth. "Fountain Flow of Water in Vertical Pipes." American Society of Civil Engineers, Trans. No. 57, p. 265-306. 1906.

$$Q = \frac{C\ A\ X \sqrt{g}}{\sqrt{2\ Y}}$$

It is interesting to note that this expression also holds for pipes discharging at an angle with the horizontal when the *X ordinate is measured parallel with the axis of the pipe and the Y ordinate is measured vertically.*

For flow in gallons per minute, with the ordinates and pipe diameter in inches, the expression is:

$$G = \frac{2.84\ C\ D^2\ X}{\sqrt{Y}}$$

For any given pipe diameter and given value of Y, the flow is directly proportional to the Y ordinate.

The flow from pipes ranging from 2 to 8 inches in diameter and values of Y of 12 and 24 inches, respectively, is given in Figure 35. Since experimental data are lacking, a value of C = 1.0 was used in computations for these diagrams.

The flow from partially filled horizontal pipes can be estimated by multiplying the flow obtained from the diagram by the percentage of the area of the pipe that is filled at the end of the pipe. The coordinates should be measured from the approximate center of the jet at the end of the pipe instead of from the center of the end of the pipe. The Purdue method described below is generally more accurate, especially for partially filled pipes.

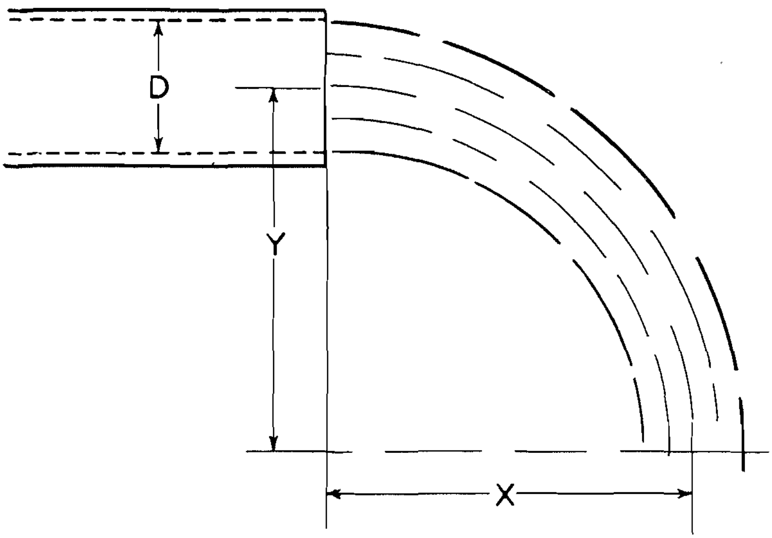

Fig. 34. Drawing showing dimensions necessary in making a measurement of the flow from horizontal pipes.

FIG. 35

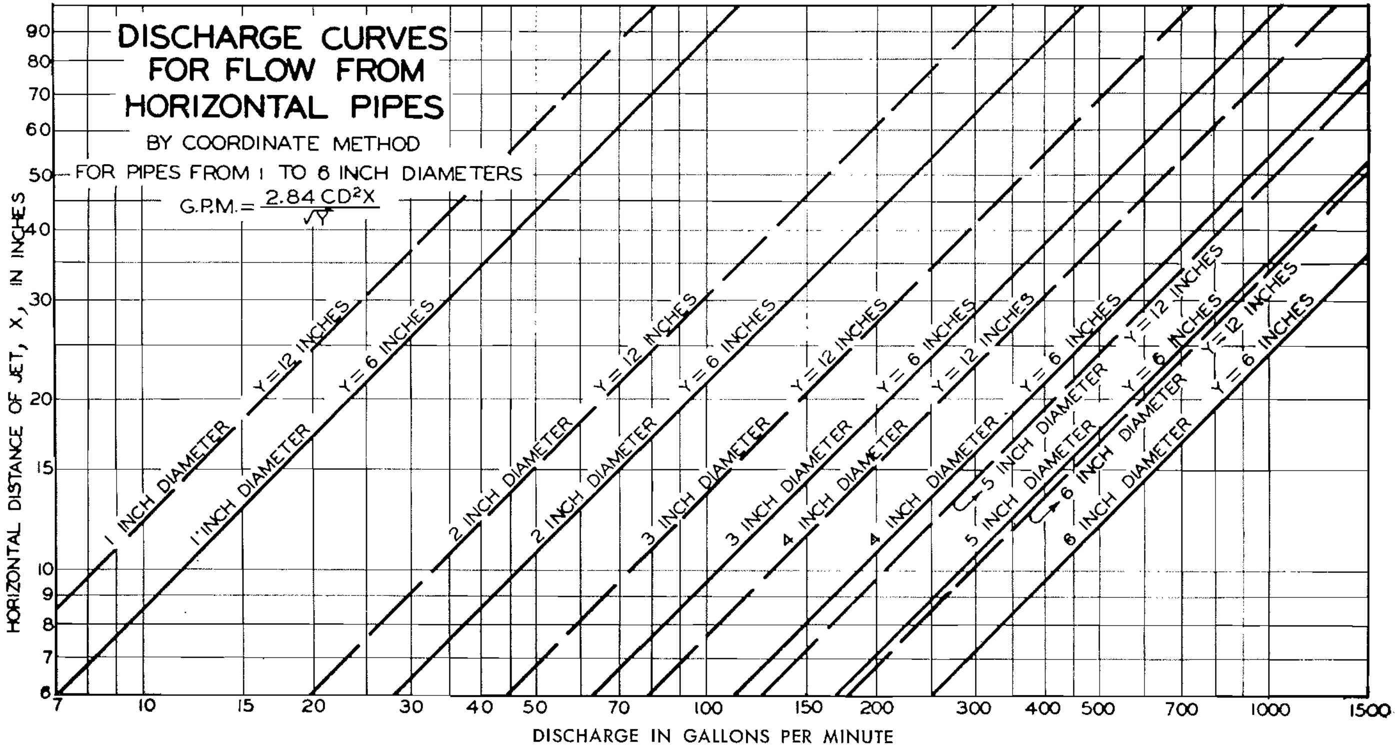

Fig. 35. Discharge curves for flow from horizontal pipes.

Purdue Method for Horizontal Pipes. Another coordinate method of measuring pipe flow has been developed at Purdue University.[11] It consists of measuring the coordinates of the upper surface of the jet as shown in Figure 36. For pipes flowing less than 0.8 full at the end, the vertical distance Y can be measured at the end of the pipe where X = O. The flow from pipes ranging from 2 to 6 inches in diameter is given in Figure 37. These diagrams were prepared from data taken from Purdue Engineering Experiment Station Bulletin No. 32, and are based on tests on standard pipe sizes only. The curves for the casing have been drawn in by interpolation.

For accurate results, the pipe must be level and of sufficient length so that the water is flowing fairly smoothly when it issues from the pipe. If the pipe slopes upward, the measurements will be too high and if it slopes downward, they will be too low. The top of the jet is not sharply defined and it is difficult to make an exact measurement of the distance Y.

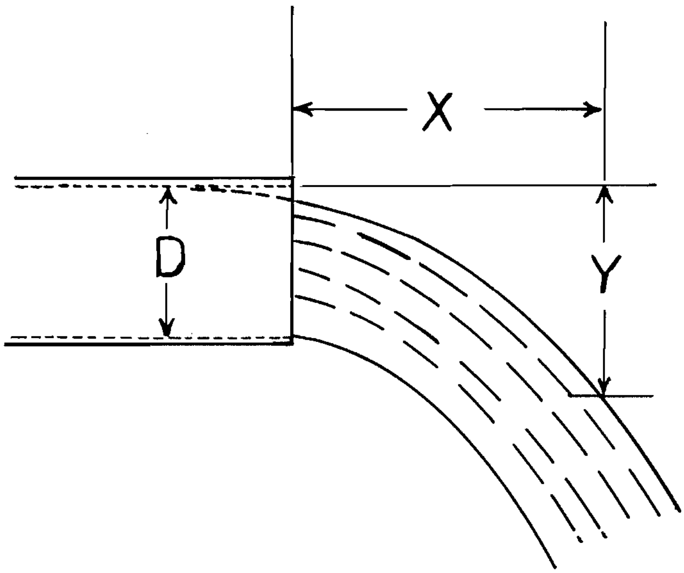

Fig. 36. Purdue method of measuring pipe flow.

[11]Greve, F. W. Measurement of pipe flow by the coordinate method. Purdue Engineering Exp. Sta. Bul. 32. 1928.

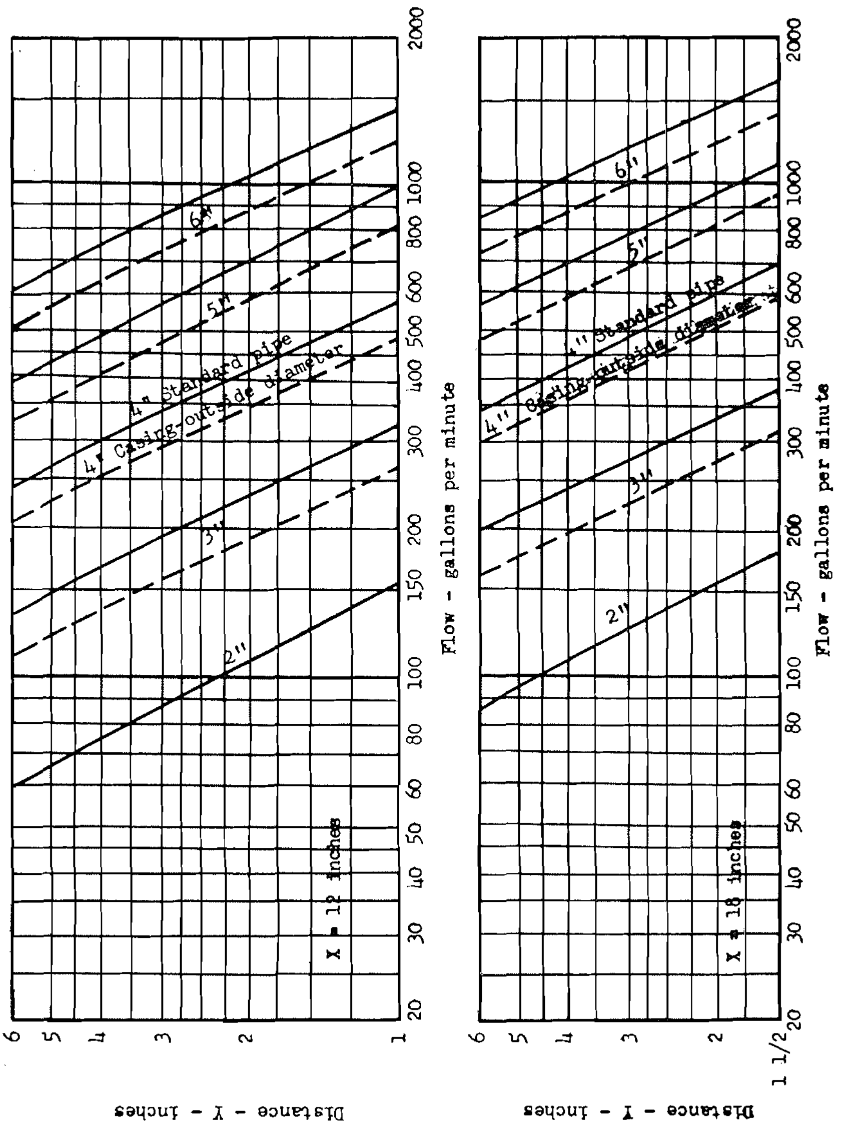

Fig. 37. Flow from horizontal pipes by Purdue coordinate method.

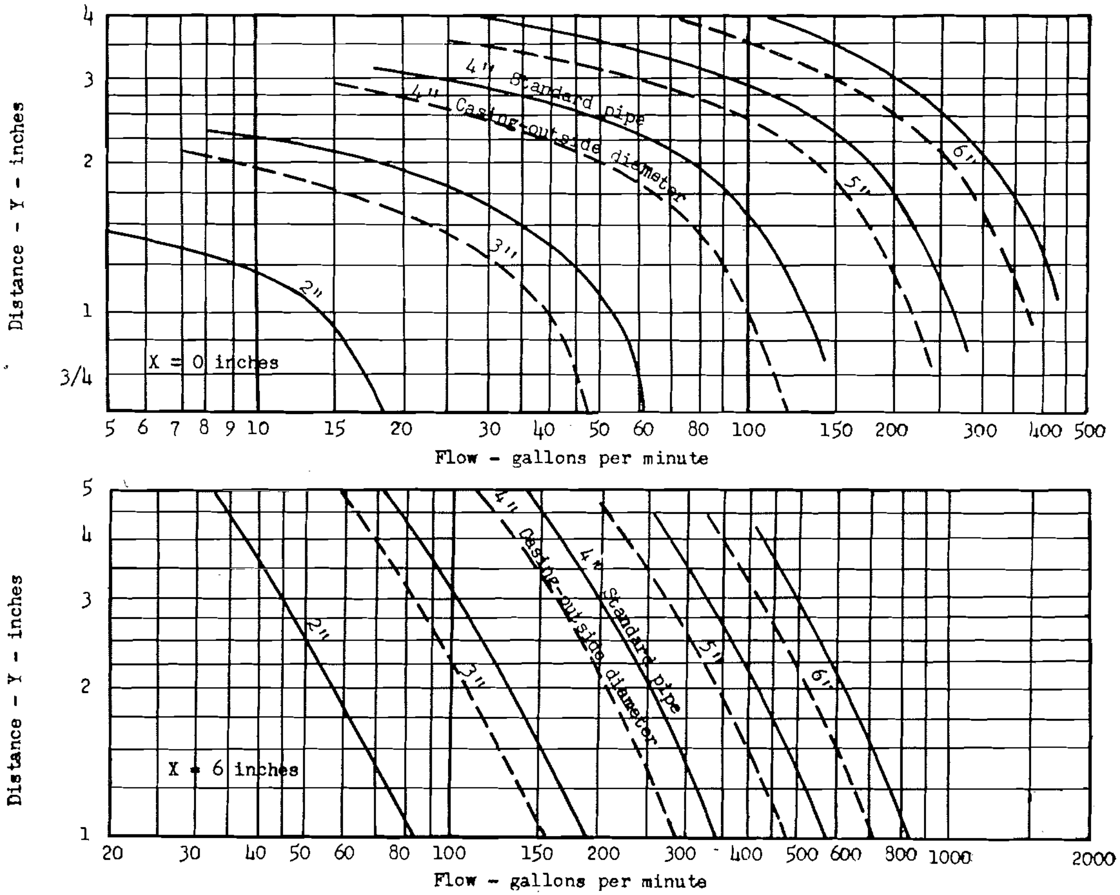

Fig. 37. Flow from horizontal pipes by Purdue coordinate method.

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